A NETWORK ANALYSIS OF SOCIAL BALANCE IN CONFLICT IN THE MAGHREB

THESIS

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Abstract

This work offers the U. S. military and national security structure a methodology to analyze tension within signed networks based on social balance theory, presents a process to partition a signed network to identify likely subsets within the network, and pinpoints unique actors and relationships based on the structure of the network. Relationships identified to cause increased tension within the network are discovered and analyzed. Identifying this tension provides analysts with insight into the complexities of the network and potential relationships to target to stabilize or destabilize a network. Two Social Network Analysis models have been developed analyzing the relationships of key actors associated with the 2012-2013 conflict in Northern Mali. Relations between the terrorist group Al-Qa'ida in the Islamic Maghreb (AQIM), several Tuareg organizations, the Malian government and other key actors are assessed, both prior to and immediately following French and other international forces involvement beginning in January 2013. The potential effectiveness of the developed methodology is demonstrated, through the Mali example, in the identification of a specific relationship between two organizations as being under tension to change; subsequently one of the organizations split, reducing the tension and irreversibly changing the network.

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I would like to thank Dr. Richard Deckro for his patience and assistance in guiding me through this process. Our conversations covering math, history, politics and war were always insightful and educational. In addition, my appreciation is extended to Dr. James Morris. His assistance and encouragement, always providing positive, constructive feedback, were influential to the successful completion of this endeavor. My sponsor, Mr. Jannarone, rallied his colleagues on many occasions in my endless pursuit for more information. Additionally, I would like to thank Dr. Robert Norton and Zachary Johnston of Auburn University who assisted me in data collection. Lastly, I am forever indebted to my wife for her support and am thankful for her joyful spirit despite late nights and long hours.

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1 Introduction

1.1 Problem Statement

A main objective of the National Security strategy released by the Office of the President of the United States (OPOTUS) is to "disrupt, dismantle and defeat al-Qa'ida and its violent extremist affiliates in Afghanistan, Pakistan, and around the world." ((OPOTUS), Office of the President of the United States, 2010, p. 19) In addition to groups in Afghanistan and Pakistan, large al-Qa'ida affiliated groups are active in Egypt (Egyptian Islamic Jihad – EIJ), Iraq (al-Qaeda in Iraq – AQI/ The Islamic State of Iraq – ISI), Yemen (al-Qa'ida in the Arabian Peninsula – AQAP), Somalia (Al Shebaab), and the Maghreb (al-Qa'ida in the Islamic Maghreb – AQIM) (Byman, 2012). Since 2001, the United States and its allies have been conducting overseas contingency operations against a variety of terrorist groups. This conflict has manifested most obviously in the wars in Afghanistan and Iraq. American soldiers withdrew from Iraq in 2011 and are projected to end combat operations in Afghanistan in 2014.

Even as these kinetic conflicts near an end, the mission of disrupting, dismantling, and defeating al-Qaeda around the world is still necessary and apparent. Future efforts in completing this mission will require the U.S. to

strengthen our own network of partners to disable al-Qa'ida's financial, human, and planning networks; disrupt terrorist operations before they mature; and address potential safe-havens before al-Qa'ida and its terrorist affiliates can take root ((OPOTUS), Office of the President of the United States, 2010, p. 21).

Due to the overwhelming military superiority of the United States and its allies, any conflicts against al-Qa'ida affiliated groups are likely to be counterinsurgencies.

United States joint doctrine defines *Counterinsurgency* (COIN) as military, paramilitary, political, economic, psychological, and civic actions taken by a government to defeat an insurgency (Joint Publication 1-02: Department of Defense Dictionary of Military and Associated Terms). An *insurgency* is an organized movement aimed at the overthrow of a constituted government through the use of subversion and armed conflict (Joint Publication 1-02: Department of Defense Dictionary of Military and Associated Terms). Since 2006 the United States Army has published two new Field Manuals on COIN, *FM 3-24: Counterinsurgency* and *FM 3-24.2: Tactics in Counterinsurgency*. In the forward of *FM 3-24*, Generals Petraeus and Amos state that "all insurgencies, even today's highly adaptable strains, remain wars amongst the people." Elsewhere *FM 3-24* states:

> Political power is the central issue in insurgencies and counterinsurgencies; each side aims to get the people to accept its governance or authority as legitimate…. Political and military leaders and planners should never underestimate its scale and complexity (2006, p. 1_1)

This quote demonstrates that COIN is essentially a fight for the people. To be successful, all aspects of government (as well as applicable non-governmental organizations) must garner a cultural understanding and create a strategy that

incorporates the complex relationships of the local population. *FM 3-24.2* states: "Since all wars are fought in and amongst a population, the Army seeks to develop an ability to understand and work with a culture for its Soldiers and leaders (p. 1_18)." In dealing with complex social environments, the U.S. must be aware of and capable of exploiting the social balance, comprising alliances and adversarial relationships, among the population. Currently, the DOD addresses the social balance of a population in an ad hoc manner leading to misunderstandings of the human environment. Actions resulting from these poor assessments can exacerbate existing tensions, create new rifts, and further damage relationships resulting in detrimental effects to U.S. objectives. This thesis presents an analytical approach to address the need to better understand the interconnected relations of people in an area of interest. While this methodology can be applied to any area of the world, Mali is used as a case study due to the unrest in the region. This unrest has been exhibited by the coup and subsequent conquering of Northern Mali by AQIM and affiliated jihadist groups, followed by the retaking of Northern Mali's main cities by the French, Malian and African forces. The situation in Mali is likely to descend into a counterinsurgency environment with AQIM and other extremist groups operating in the vast desert against Malian and international forces that control the cities.

1.2   The Adversary

AQIM is an Al-Qaeda affiliated terrorist organization born in Algeria that now operates across much of North and West Africa. It is focused on establishing an Islamic

Caliphate and conducting jihad against anyone opposed to their mission (Benjamin, 2012). Recently AQIM and affiliated groups have become popular in the western media due to their kidnapping of Westerners for ransom, for capturing and controlling Northern Mali, for their alleged involvement in the terrorist attack in Benghazi, Libya on September 11, 2012, and the attack on an Algerian natural gas plant in January 2013 that resulted in 37 hostage and 29 militant deaths. Since 2008, AQIM is reported to have raised tens of millions of dollars through kidnapping operations alone (Cohen, 2012). The territory captured in Northern Mali, roughly the size of Texas or France, provided Al-Qaeda with its largest sanctuary since Afghanistan prior to 2002. The actions of the Islamists in Northern Mali, instilling Shari'a law and destroying UNESCO historical and religious sites have raised alarms and harkened comparisons to the Taliban's actions in Afghanistan prior to September 11, 2001. An Amnesty International report released on 20 September 2012, states nearly 436,000 people have fled Northern Mali for the south or neighboring countries (Amnesty International, 2012). Additionally, militant groups are well armed thanks to the recent fall of Gaddafi in nearby Libya and the capture of Malian army stockpiles (Arieff & Johnson, August 2012). The combination of extreme ideology, a sanctuary for training, a good financial basis, and large amounts of weapons and experience makes AQIM and other extreme Islamic militant groups a serious threat to the region and the world.

Throughout 2012 the international community assessed the situation and considered plans to regain the lost territory. In January 2013, as the Islamists threatened to move further south towards the capital of Bamako, France intervened in

the conflict. Intense fighting has taken place, first between local groups, and more recently against the international forces. As this conflict unfolds, a cultural study of the people of Mali will provide needed insight on the complex relationships at work in the region. In the forward of FM 3-24, Generals Petraeus and Amos state that "conducting a successful counterinsurgency campaign requires a flexible, adaptive force led by agile, well-informed, culturally astute leaders."

This thesis presents a methodology that, when properly applied, will assist strategic leaders by providing insight into the complex intricacies of an area of interest. The approach presented in this study provides an analytic process that detects alliances present in the operating environment, identifies unique actors, such as mediators, and pinpoints vulnerable relationships based on the structure of the network.

1.3   Problem Approach

Many studies have been conducted attempting to identify statistically significant factors which can be used to properly predict upcoming ethnic conflicts (Szayna, 2000; O'Brien, 2002; Goldstone, *et al*., 2010). However, once a country or region is identified as being at risk, few models are capable of evaluating the multifarious relations that exist within that area. Network analysis often only considers if a relationship exists. If two actors have a relationship then a connection between them is drawn. In reality, however, people have both positive and negative relations. A much different relationship exists if two actors like each other than if they dislike each other. Particularly in an environment where there is obvious tension, the *type* of relationship

needs to be considered when conducting an analysis on a network in order to gather information on how relationships affect the network as a whole.

Once positive/negative relationship data is collected, a signed adjacency matrix is constructed from the data and a directional signed network is created. Since most real-world large networks are unbalanced, Heider's structural balance theory (Heider, 1946) can be used to recognize and study unbalanced relationships. If a relationship that causes imbalance does not change, then it is a source of tension within the network. As relationships in the network are identified as having the potential to change to make the network more (or less) balanced, they can be evaluated by intelligence analysts. If these relationships can and do change as predicted, then the network can become more (or less) balanced, resulting in less (or more) tension and cause for conflict in the region. Making a hostile network less balanced could result in increasing tension within the network and achieve destabilizing goals. Additionally, the network can be separated into subsets thereby identifying important alliances, enemies and mediators. To aid the analysis, a balance index will indicate how balanced the network is and centrality measures can identify key actors within the network.

A balanced signed network can be partitioned into two distinct subsets where each subset has positive relations within the subset and negative relations with each actor in the other subset (Harary, 1953). When a signed network is unbalanced, clustering of more than two groups can be done if the network has no cycles which have exactly one negative arc (Davis, 1967). The Doriean/Mrvar algorithm can be used to determine if a network is balanced, how balanced it is at a given number of subsets, and

identifies the best number of subsets to partition a network into. Blockmodeling can then be used to identify which relationships cause imbalance within the network. Relaxed blockmodeling is also used to account for factors other than structural balance in the model. This method relaxes the requirements of structural balance to allow for the grouping of actors who have identical or similar ties to and from all actors in other groups. These techniques can aid in identifying alliances or analogous actors by grouping them into appropriate subsets based on their relations (Wasserman & Faust, 1994, p. 396). Additionally, it identifies specific relationships that may be vulnerable to change or potential misrepresentations within the network.

1.4 Assumptions

Like most models, this model is only as good as the data that is collected and analyzed. Subject Matter Experts (SMEs) should be included in the data collection and assist in validation and verification of the model to ensure that substantive conclusions are drawn. The proposed model is designed to provide insight to analysts; it should not be used as the ground truth or for operational decisions based solely on its results. A number of assumptions are made to enable the methodology of the model. First, human behavior is assumed to be rational. If it is not rational, then it is unpredictable and therefore impossible to accurately model. In most situations humans make rational decisions; however, in some situations this assumption may not hold true. Another assumption is that a proper decision making process was conducted to identify the appropriate groups, actors or nodes to include into the model. Depending on the

application, actors could be individuals, tribes, ethno linguistic or other people groups that are influential within the societal network. When appropriate data is unavailable, subject matter experts (SMEs) must provide historical and cultural data on the relationships between cultural groups within the region of interest. This data consists of positive and negative relationships between the groups in the study.

1.5   Overview and Format

Having defined the problem and outlined the general analysis approach, this thesis next provides a review of the supporting literature on the topics covered. Chapter Two presents an overview of AQIM, highlighting its structure and leaders, regional dynamics, affiliates and off-shoots, a historical context to the conflict in Mali, as well as United States efforts in the region. Additional topics within Chapter Two include dark social networks, graph theory, structural balance theory, identifying subsets within signed networks, measuring imbalance, partitioning a signed network, and social network analysis metrics applicable to signed networks. Chapter Three develops the methodology for partitioning and assessing signed social networks. Chapters Four and Five apply the methodology to the situation in Mali by analyzing the relationships between militant groups within Mali. Conclusions are made in Chapter Six as well as recommendations for further research.

2 Literature Review

2.1 Introduction

This chapter provides an overview of AQIM and the conflict in Mali, outlines the basic framework of Social Network Analysis (SNA), and highlights relevant previous work done on Social Networks, signed graphs, and social balance theory that support the development and application of the methodology used with the thesis. The author directs readers to Wasserman and Faust (Social Network Analysis: Methods and Applications, 1994), Hanneman (Introduction to Social Network Methods, 2005), and Scott and Carrington (The SAGE Handbook of Social Network Analysis, 2011) for more detailed explanations of SNA methods.

2.2 Background and Overview of Al-Qa'ida in the Islamic Maghreb (AQIM) and the Conflict in Mali

The roots of AQIM can be traced back to the turmoil in Algeria in the 1980's and 1990's. Having gained their independence from France in 1962, Algeria had been functioning as a one party system until President Bendjedid introduced political reforms including multi-party elections (Harmon, 2010, p. 13). As a result, the Islamic Salvation Front (FIS) became Algeria's first official Islamic political party in 1989. The FIS won the municipal elections in 1990 and a majority of the 1991 first round elections. In 1992, prior to the second round elections in which the FIS was predicted to win again, a military junta seized power. The military deposed President Bendjedid, outlawed the FIS, imprisoned its leaders and detained thousands of Islamic activists in Saharan

concentration camps (Harmon, 2010, p. 14). The denial of a democratically elected

Islamic government, coupled with the influence of extreme Islamists wanting to

establish an Islamic caliphate, resulted in a blossoming movement of militant Islam

within Algeria in the early 1990's.

At this same time in Algeria there were Islamic extremists returning from

Afghanistan, following the Soviet withdrawal in 1989. An estimated 1,000 to 1,500

mujahedeen who fought in Afghanistan returned to Algeria after Pakistan ended

mujahedeen operations in their country (Kohlmann, 2007, p. 2). These Afghan fighters

returned to Algeria with military skills to incorporate into training camps and extremist

plans to evoke an Islamic revolution (Dahlburg, 1996; Compass, 1994). The combination

of returning Afghan mujahedeen and domestic Islamic persecution by the Algerian

government provided the environment for the formation of the armed Islamic terrorist

groups.

In the early part of the 1990's, many different militant factions were fighting the

government of Algeria. In late 1992 several factions, which included former Afghan

fighters, combined to form the Armed Islamic Group (GIA) (Kohlmann, 2007, p. 3). The

GIA began conducting attacks in 1993 and practiced an extreme version of Islam called

Salafism[1]. The GIA made a number of high profile attacks including a hijacking of an Air

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[1] Salafism called for a return to traditional Islam, the Qur'an, and the practices of the prophet Mohammed or the Sunnah (Botha, p. 12). At the decline of the Ottoman Empire Muslim scholars became concerned that the Muslim world was falling behind the rest of the world. Attributing the decline to a departure from the straight path of

France flight from Algiers to Paris in 1994. Attacks on the civilian populace caused a rift

between the FIS and the GIA causing the FIS to form their own armed group, the Islamic

Salvation Army (AIS), in 1994. The goal of the AIS was to overthrow the Algerian

government to allow FIS to establish an Islamic government. The FIS wanted to

separate themselves from the violence that the GIA was conducting on civilian targets.

The AIS leadership believed in attacking military and government targets only and

allowed for the opportunity to return to the political process (Harmon, 2010, p. 14).

Conversely, the GIA believed in using violent means to establish a strict Islamic

government in Algeria and were not interested in a political process.

As the GIA became more extreme, their focus switched from overthrowing the

Algerian government to their opposition with the AIS (Harmon, 2010, p. 14). In 1996,

the GIA declared war on the AIS and in 1997 issued a fatwa (Islamic ruling) condemning

the entire population of Algeria for not supporting them. In 1996 and 1997, there were

over forty separate massacres of civilians, most attributed to the GIA (Harmon, 2010, p.

14). By the end of the 1990's, the GIA had lost much of the power they once had due to

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Islam, a revival of Islamic thought took place leading to Salafism. The most extreme
form of Salafism, the kind practiced by jihadists, is unwilling to work within the secular
political system to achieve their objectives. These extremists believe that the legitimacy
of Muslim governments is based on Shari'a law and that those people that do not follow
it explicitly are unlawful and must be removed (Botha, June 2008, p. 17). Using this
same logic, extremists often attack fellow Muslims, even though it is explicitly not
permitted in Islam. They justify their attacks by declaring people or governments as
non-Muslim if their actions or statements fall beyond the framework of Islam.

the success of the army's "eradication" policy against terrorists, the GIA's increasingly erratic and extremist leadership, and its violent tactics particularly against civilians (Cristiani & Fabiani, 2011). Although the GIA was never officially dissolved, it was an inept organization by 2001 (Kohlmann, 2007, p. 12) and is no longer on the State Department's list of Foreign Terrorist Organizations (FTOs).

While some mujahedeen decided to accept the amnesty offered by the Algerian government when the GIA self destructed, not all were willing to give up the fight. In 1998, former GIA member Hassan Hattab founded the new group, the Salafist Group for Call and Combat (GSPC).[2] The GSPC wished to return to the goal of removing the Algerian government and instating a fundamental Islamic government while avoiding the unnecessary targeting of civilians. Within a few years the GSPC grew in numbers to around 3,000, as former GIA and AIS fighters unified under the common goal (Kohlmann, 2007, p. 13). In 2003 Hattab was removed from leadership because he wanted to maintain focus in Algeria as opposed to the global jihad of Al-Qa'ida (Botha, June 2008, p. 64). This demonstrated a rift in the group and shift in the group's focus from the near enemy (Algeria) to the far enemy (France and the United States). The new leader Nabil Sahrawi (a.k.a. Abu Ibrahim Mustafa) was killed in 2004. Abdelmalik Dourkdal (a.k.a. Abu Musab Abdel Wadoud) became the next leader and saw the transition of the organization from GSPC to AQIM. There were many factors that led the

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[2] The Salafist Group for Call and Combat is also known as the *Salafist Group for Preaching and Combat* or *Le Groupe Salafiste pour la Predication et le Combat* in French.

GSPC to join the Al-Qa'ida network. Undoubtedly, the U.S. wars in Iraq and Afghanistan were a contributing factor to the transformation to global jihadism. There is a great deal of evidence that the GSPC and Al-Qa'ida in Iraq (AQI) had a relationship to recruit Algerians to fight in Iraq (Kohlmann, 2007, pp. 17-18). Some recruits were sent to Iraq, while others were kept in Algeria to increase the manning of the GSPC.

On 11 September 2006, Al-Qa'ida's second in command, Ayman al-Zawahiri, announced the merger of GSPC with Al-Qa'ida. In January 2007 the GSPC announced their new name: Al-Qa'ida in the Islamic Maghreb. The name change reflected the evolution of the goal of the organization from local to global jihad. The group then began to target foreign countries and operate outside the borders of Algeria, especially in Mali and Mauritania (Harmon, 2010, p. 16).

Between 2008 and 2011, the Global Terrorism Database lists 184 attacks attributed to AQIM. Nearly 84% of the attacks took place in Algeria, many of them against government, military or police forces (see Figure 1) (Global Terrorism Database, 2012).
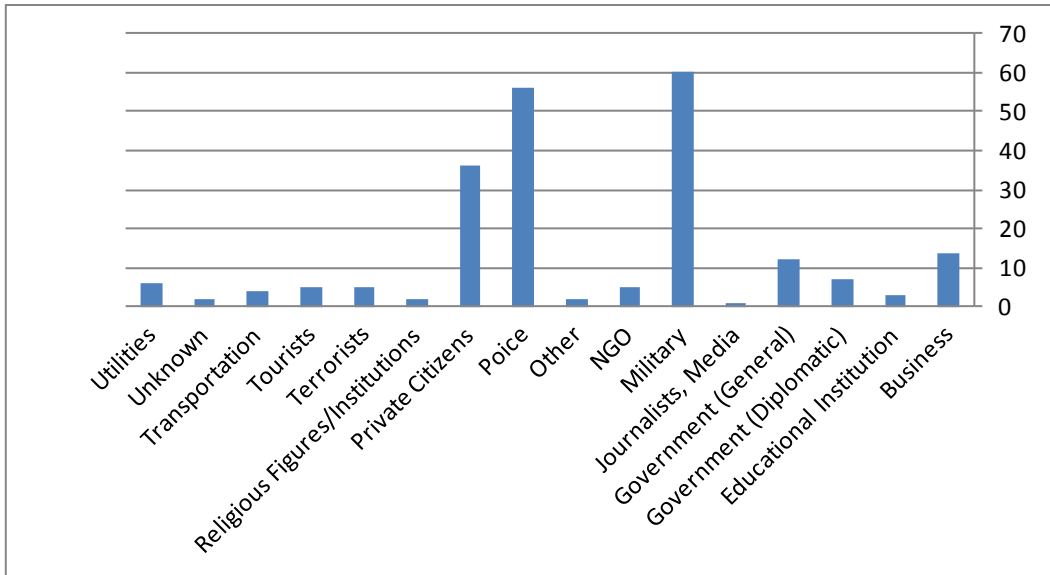
Figure 1: AQIM Attacks by Target: 2008-2011 (Global Terrorism Database, 2012)

In 2007, AQIM had three attacks in Algeria that claimed over 30 lives including a double car bombing against a bus and a UN building. In August 2008 over 100 people were killed in blasts east of Algiers. Italian, Spanish, French, German, Canadian, Swiss and British civilians have been kidnapped over the past 5 years. Several hostages were killed after failed raids trying to save them. However, most hostages were released after negotiations. Reports state that significant ransom payments and the release of imprisoned AQIM individuals have been commonly provided to AQIM in return for western hostages. In July 2012, two Spaniards and an Italian woman were released by MUJAO, an AQIM affiliated group, after being held since October 2011. An AQIM spokesman said that they received $18.3 million and one person released from a Mauritania prison (AFP, 2012). An estimated $89 million has been paid to AQIM between 2004 and 2011 (Blair, 2013).

Grynkewitch and Reifel (November 2006) established a model to determine the finances of the GSPC. While their work was conducted in 2006 on the GSPC, many of their assumptions hold true today for AQIM. Table 1 describes the projected income sources from Grynkewitch and Reifel with the exception of the High Value Kidnapping/Individual value. The High Value Kidnapping/Individual value listed in the table is based on the approximately six million dollar per person reportedly paid for the Spanish and Italian hostages released in July 2012 and is about twice the value calculated by Grynkewitch and Reifel. The model that Grynkewitch and Reifel developed came up with the recommendation for Algeria to attempt to decrease GSPC's (AQIM's) ability to smuggle because it was a large portion of their income. However, as they have been able to obtain larger amounts of ransom money than Grynkewitch and Reifel predicted, smuggling may now be less important than kidnappings. In the past a large portion of smuggling was believed to be cigarettes. However, in recent years there have been reports and some evidence of cooperation with Latin American drug cartels (UPI, 2010). It is believed that drugs come in through Mauritania, are trafficked through the porous trade routes of the Sahara under protection of AQIM and other groups, and end up in Europe. If this is true, then AQIM is likely receiving large amounts of cash and weapons from a previously unrealized source.

Table 1: Projected AQIM Income Sources and Amounts

Income	Source
$5,000	Local Extortion/ Incident
$5,000	Local Kidnapping/ Incident
Food & Shelter	Local Populace
$2,750,000	Annual Smuggling
$6,000,000	High Value Kidnapping/individual
$148,000	Diaspora support from Europe

2.2.1   AQIM Structure.
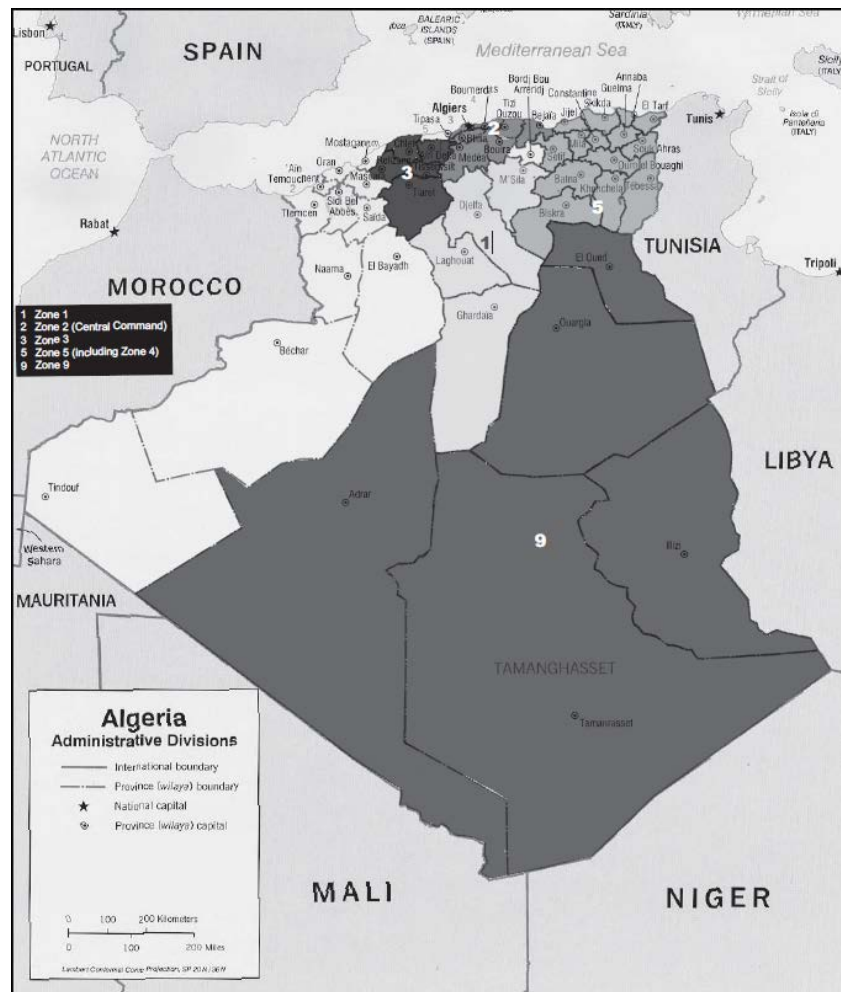
Figure 2: GSPC Zones of operations (Source: Botha p. 46)

The GSPC was structured into zones as depicted in Figure 2. Often, when talking about operations within a certain zone in Algeria, the GSPC numbers are still used. However, it is believed that AQIM has restructured into regional zones: Central – Algeria, East – Tunisia, West – Mauritania, and South – The Sahel (Botha, June 2008, p. 50).

An emir heads each zone, which is further subdivided into *katibats*, or companies, with each *katibat* subdivided into three or four *fassilas*. A *fassila* in turn is made up of two *sarayas*, each with 12–18 members, often working in smaller groups of between two and six members (Botha, June 2008, p. 46). This hierarchical structure is reminiscent of a military organization which allows for good command and control as well as a potential for individuals or small groups to act independently with occasional guidance from higher. The central, Algerian, zone has been less active in recent years due to increased pressure, including many high profile arrests, from Algerian forces. The southern and western zones have become areas AQIM has been able to expand operations in recent years.

2.2.2 AQIM Leadership.

Abdelmalik Dourkdal (a.k.a. Abu Musab Abdel Wadoud) has been the leader of GSPC/AQIM since 2004. Dourkdal was born in the Blida region of Algeria in 1970. In 1989, he earned his bachelor's degree in Mathematics. From 1990-1993, he studied chemistry and electrical engineering at the University of Blida. In 1993, Dourkdal joined the GIA, working with explosives. By 1996 he was placed in charge of training courses for the al-Ahwaal Brigade in the second zone. Later he commanded the Al-Quds

Brigade. In 2001, Dourkdal joined the GSPC and served in the second zone (Kohlmann, 2007, p. 15). After taking command of the GSPC in 2004, Dourkdal has expanded the area of operations of the GSPC/AQIM outside of Algeria and evolved their tactics to include suicide bombings and vehicle borne improvised explosive devices (VBIEDs).

Mokhtar Belmokhtar (a.k.a. Khalid Abu al-Abbas; Khaled Abu Abbes; Laaouar or Belaouer ('One Eyed'); Mr. Marlboro) has been a key leader of AQIM since its inception, operating in Southern Algeria and Northern Mali, and commanding of the El Moulethemine battalion. He was born in 1972 in central Ghardaia, Algeria. According to an interview, he claims he went to Afghanistan at the age of 19 to train and then fight. While there he met a number of prominent jihadists from around the world and is believed to still maintain contact with Al-Qa'ida central. He returned to Algeria in 1992 and served in the southern zone of the GIA, GSPC and AQIM (Black, 2009). Belmokhtar operates in northern Mali and is well known for kidnappings and trafficking of weapons and materials throughout the Sahara and Sahel regions. He has four wives from the local Tuareg and Arab communities that help to provide him with connections (Black, 2009). Belmokhtar is thought to have connections within the Mali government and military as well. He reportedly has had a falling out with the AQIM leader, Dourkdal, but still maintains connections and influence within AQIM providing them with money, weapons and materials. In December 2012, Belmokhtar split from AQIM in order to form his own organization "Mouakaoun Bidima" the "Signatories by Blood." (Jamestown Foundation, 2012) This organization has been closely allied with another AQIM offshoot, MUJAO, and described in more detail in Section 4.3.

2.2.3   Regional Dynamics.

The Maghreb countries consist of Libya, Tunisia, Algeria, Morocco, Mauritania and the disputed territory of Western Sahara[3]. Generally there are bands of eco-regions across the continent as a Mediterranean climate in the far north yields into the Saharan desert in the south. The Sahara is the largest desert in the world stretching across North Africa comprising most of Western Sahara, Mauritania, Northern Mali, Algeria, Niger, Libya, Northern Chad, Northern Sudan, Egypt and Eritrea. South of the Sahara running at 10 to 15 degrees North Latitude, is the Sahel. The Sahel has the Sahara located to the north and the less arid savannah on its south.

North Africa has been a melting pot of cultures dating back to before the time of Christ when Carthage was established by the Phoenicians. Many different kingdoms have ruled the region including the Berber kingdom of Numidia, the Roman Empire, the Germanic Vandal Kingdom, the Byzantine Empire, the Islamic Caliphates and Emirates, the Ottoman Empire and, most recently, colonial France, Spain and Italy. The Sahara has historically been mostly unpopulated, serving as a physical barrier between the population centers in the Northern Maghreb countries and the population centers south

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[3] Western Sahara is an unstable country in West Africa on the coast between Mauritania and Morocco. Morocco has annexed or laid claim to the entire country, but the Polisario Front has actively resisted annexation. A civil war between Morocco and the Polisario Front ended in a UN brokered ceasefire in 1991. The Polisario Front was formed to represent the people of Western Sahara when the Spanish relinquished control of the colony. The Polisario Front is backed by Algeria and is based in Tindouf, Algeria. The Polisario Front is a group focused on the freedom of Western Sahara and does not have known Islamic extremist goals. Although there is fear that the Polisario camps have become a recruiting ground for AQIM and other extremists (Alexander, 2012).

of the Sahel. Nomadic people have traditionally operated trade routes through the desert to link the otherwise distant populations.

Figure 3: Map of Africa showing the Sahara desert and the Sahel (World Atlas, 2013)

The Maghrebian people are mostly Arab and Berber with some European and many different Sub-Saharan cultures. The entire region is predominantly Muslim. Niger has the largest non-Muslim population in the region (20%), followed by Mali (10%) (CIA World Factbook, 2012).   Mauritania is classified as having a mixed Moor and black population. Mali and Niger are made up of a wide variety of ethnic groups. With the exception of Tunisia (who's population is classified solely as Arab), the population in

North Africa is almost completely classified as Arab-Berber. Arab-Berber's are mostly

Berber in origin, but most identify themselves as being Arab. Berber is a name for a

wide variety of nomadic and semi-nomadic tribes in North Africa. Historically the Berber

people spoke the Berber language, although now many speak Arabic and sometimes

French as well. Some of the most populous Berber groups are the Kabyles in Northern

Algeria, the Shawia (also spelled Chaouia) of Northeastern Algeria, the Haratin, Rif,

Berabers, and Ishelhiyen (Shluh) in Morocco, and the Tuareg in the Sahara

(Encyclopædia Britannica, 2013).   The Tuareg are a large group of pastoralist people in

North Africa, located mostly in Algeria, Mali and Niger, as shown in Figure 4.
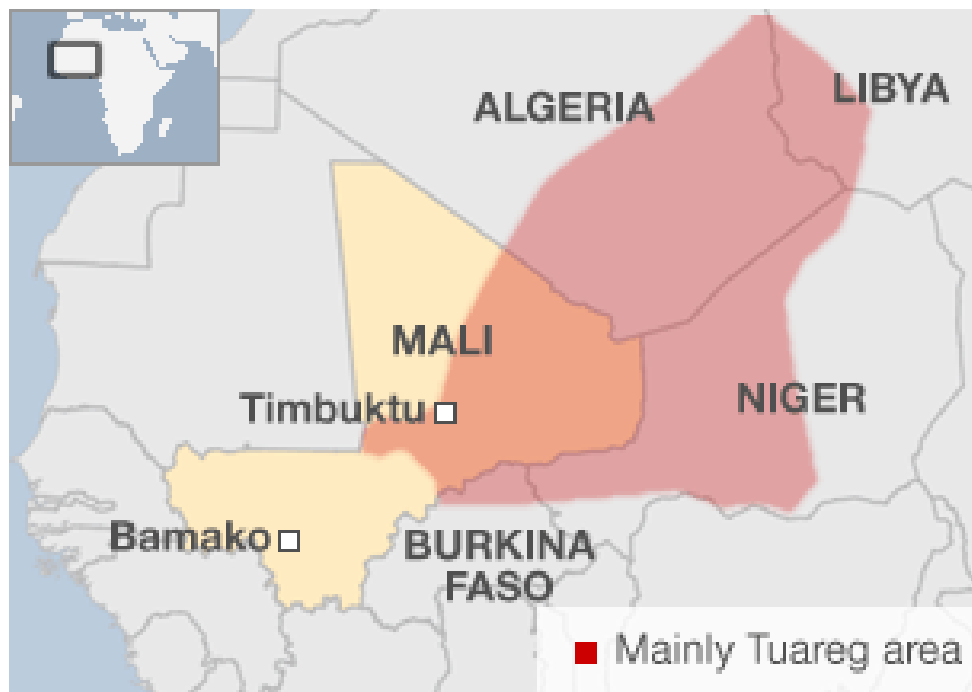
Figure 4: Mainly Tuareg Area of North West Africa (Melly, 2012)

The economies of the countries in which AQIM has influence can be divided into

two separate categories, poor countries in the Sahara and North African hydrocarbon

and market oriented economies. The poor Saharan countries are Mali, Mauritania and

Niger. Mauritania is the only country out of the three that is not landlocked. All of

these countries heavily depend on international money in order to function. All of the

countries are believed to have sizeable reserves of minerals: iron ore in Mauritania, gold

in Mali and uranium in Niger. Despite the mineral wealth, given the subsistent nature of

the majority of their populations and the risk to foreign investment, these countries will

likely continue to be poor for the foreseeable future. The North African countries can

be split into two groups: oil countries and market oriented countries. The economies of

Libya and Algeria depend heavily on oil and natural gas. Whereas Tunisia and Morocco

have developed market oriented economies with agriculture, mining, tourism, and

manufacturing as contributing factors (CIA World Factbook, 2012). With the recent

turmoil in Libya and Tunisia, their economies have slowed and less reliable statistics are

available. High levels of unemployment throughout the region are often cited by

experts as a contributing factor to disgruntled young men's recruitment by extremist

groups. Table 2 outlines the GDP, GDP growth rates, unemployment rates, literacy,

average age, and life expectancy of each of the countries where AQIM has influence.

Table 2: Significant Economic Figures for countries where AQIM has influence (CIA World Factbook, 2012)

Country	GDP (2011)	Rank in World	GDP Growth Rate (2011)	Unemployment Rate (2011)	Literacy	Average Age	Life Expectancy
Algeria	$267 Billion	49	2.50%	10%	69.90%	28.1	74.73
Libya	$37.97 Billion	101	2.5% (2010 est)	30%	89.20%	24.8	77.83
Mali	$18.1 Billion	134	2.70%	30% (2004 est)	31.10%	16.4	53.06
Mauritania	$7.184 Billion	155	3.60%	30% (2008 est)	58%	19.6	61.53
Morocco	$164.7 Billion	59	4.30%	8.90%	56.10%	27.3	76.11
Niger	$11.78 Billion	149	2.30%	N/A	28.70%	15.2	53.8
Tunisia	$102.3 Billion	71	-0.80%	18%	74.30%	30.5	75.24
Western Sahara	$906.5 Million	203 (2007)	N/A	N/A	N/A	20.5	61.52

2.2.4   AQIM Affiliates and Off-Shoots.

The National Movement for the Liberation of Azawad (MNLA), Ansar Al-Din, The Movement for the Oneness and Jihad in West Africa (Jamaat Tawhid wal Jihad fi Garbi Ifriqiya) (MUJAO), Signatories for Blood Battalion, and Boko Haram are militant groups affiliated (to various extents) with AQIM. All of these militant organizations are introduced in this section. MNLA, Ansar Al-Din, and MUJAO are discussed in more detail in Section 4.3.

2.2.4.1   National Movement for the Liberation of Azawad (MNLA).

The National Movement for the Liberation of Azawad (MNLA) is a largely secular group whose goal is to liberate and establish a separate government in the area they

refer to as Azawad. Azawad is the desert region in Northern Mali. The movement is largely made up of ethnic Tuareg fighters. The MNLA fighters consist of people who participated in the last two rebellions (1990's and 2006), people who fought on both sides of the recent Libya war, volunteers from other ethnicities in the region, and defected soldiers from the Malian army (Attaher, 2012). The MNLA, with Islamist extremist help, began its most recent rebellion in early 2012. The Malian military, after initial attempts to stifle the rebellion, was overwhelmed by the firepower, organization, and effectiveness of the rebel fighters. On 22 March, the Malian army overthrew the government, in part because of the lack of support provided to the military to fight the rebellion. Sidetracked by the coup, poorly equipped, and facing a well armed and formidable opponent, the Malian military lost control of all of Northern Mali to the MNLA. In April 2012, the MNLA issued a declaration of independence for Azawad. Disagreements between the MNLA and the more extreme Islamic groups that assisted the rebellion resulted in conflict between the rebels. By the end of June, the MNLA lost control of much of Northern Mali to the extreme Islamic groups of AQIM, Ansar Al-Din, and MUJAO (BBC News, 2012). See the map in Figure 5 for the portion of Mali lost to the MNLA and other groups.

Figure 5: Map depicting the territory in Northern Mali (Azawad) controlled by the MNLA and then Islamist groups. (The Economist, 2012)

2.2.4.2   Ansar Al-Din (AAD).

The Ansar Al-Din ("Supporters of Religion" or "Defenders of Faith") is a new organization inside Mali established in 2012 by Iyad Ag Ghaly, one of the leaders in the Tuareg rebellion in the 1990's. There are strong indications that Ansar Al-Din is associated with AQIM based on their common goal of establishing an Islamic state and the connections of Ag Ghaly with one of AQIM's leaders, Hamada Ag Hama. The Ansar Al-Din fought alongside the MNLA in Northern Mali, but after taking control of Azawad, the differences between MNLA and Ansar Al-Din became too great. In the Battle of Gao, on 27 June 2012, Ansar Al-Din and MUJAO defeated the MNLA and took control of the main cities in Northern Mali(BBC News, 2012). Ansar Al-Din and MNLA are both led by individuals from the Ifoghas Tuareg tribe, making them close despite the conflict.   Ansar

Al-Din's goals differ from the MNLA in that they want Mali to remain united and for Shari'a law to govern the whole country (BBC News, 2012). Ansar Al-Din has operated primarily in the Timbuktu and Kidal regions of Northern Mali and has been imposing the harshest version of Shari'a law (Reuters, 2012).

2.2.4.3 Movement for Oneness and Jihad in West Africa (MUJAO).

The Movement for Oneness and Jihad in West Africa (Jamaat Tawhid wal Jihad fi Garbi Ifriqiya) (MUJAO) is an AQIM off-shoot in West Africa. The organization is led by Mauritanian national Hamada Ould Mohamed Kheirou (a.k.a. Abou QumQum) and is seen by many as a way to expand the mission of AQIM. Other analysts see the creation of MUJAO as evidence of AQIM splintering due to the native Algerian leadership's unwillingness to allow non-Algerians to rise through the ranks (Idoumou, 2011). MUJAO has made several major headlines since their inception. The first was in reference to three hostages taken from a refugee camp in southern Algeria in October 2011. The three were released on 20 July 2012 in a prisoner exchange and a reported ransom of $18.4 million (The Associated Press, 2012). This shows that the MUJAO has adopted tactics similar to the AQIM to finance their operations. The second headline was a suicide attack that MUJAO claimed responsibility for in Ouargla, Algeria. It took place on 30 June 2012 against the Algerian national gendarmerie headquarters in which a man drove a Toyota 4x4 packed with 1,300 kg of explosives into a police facility. The attack killed one and injured three policemen (Magharebia, 2012). MUJAO's participation with Ansar Al-Din in defeating the MNLA in northern Mali has caused many

to wonder what connections exist between MUJAO, Ansar Dine and AQIM or if they are different parts of the same organization. MUJAO has been operating primarily in the Gao region of Mali and have enforced Shari'a Law within the cities under their control (Reuters, 2012).

2.2.4.4 *The Signatories for Blood Battalion.*

The Signatories for Blood Battalion, led by Mokhtar Belmokhtar, is a recent addition to the extreme Islamic groups operating in the region. They officially split from AQIM in December 2012. As previously discussed, Belmokhtar has been a longstanding AQIM emir operating in the porous Saharan desert from Southern Algeria and Northern Mali east to Southern Libya. Due to his experiences and connections from working in the region, Belmokhtar's organization has instant credibility. The Signatories for Blood Battalion is closely aligned with another AQIM offshoot, MUJAO. Their first high profile operation was an attack on the In Amenas gas plant in Algeria resulting in nearly 800 initial hostages in which at least 37 hostages and 29 militants died (Jegarajah, 2013).

2.2.4.5 *Boko Haram.*

Boko Haram is an Islamist terrorist organization located in northern Nigeria. The goal of Boko Haram is to overthrow the Nigerian government and establish a pure Islamic state. Boko Haram has had several high profile attacks including bombing a UN compound in Abuja, numerous police stations and churches and most recently setting schools on fire. They have publicly declared war on Christians within the country and have caused many to move to the southern part of the country. Boko Haram is a local

terrorist group and focuses almost exclusively on Nigeria (Walker, 2012). None of their rhetoric has been in concert with Al-Qa'ida's global jihad. However, there has been evidence of communication and cooperation between Boko Haram and AQIM. Just recently, General Ham, the commander of AFRICOM said, "Most notably I would say that the linkages between AQIM and Boko Haram are probably the most worrisome in terms of the indications we have that they are likely sharing funds, training, and explosive materials that can be quite dangerous (Doyle, 2012)." Boko Haram's leader and Nigeria's president have made claims that Boko Haram is linked to AQIM. However, since Boko Haram may be trying to increase its popularity on the world stage and Nigeria is trying to get foreign funding, it is difficult to know the truth. What is known is that Boko Haram is capable of executing terrorist acts and is a serious threat to the stability of Nigeria. If the group decides to expand their area of operations and begins to work closer with other African jihadist groups like AQIM or Al-Shabab, then the situation could grow even worse.

2.2.5 Historical Context of Mali Conflict.

French influence in Africa cannot be overstated as they have had African possessions since the 17th century. Although much of West Africa gained independence from France around 1960, France continues to have influence in the area. Many of the countries still use French as their official language (see Figure 6) and others, being former French colonies, still have many French speakers.
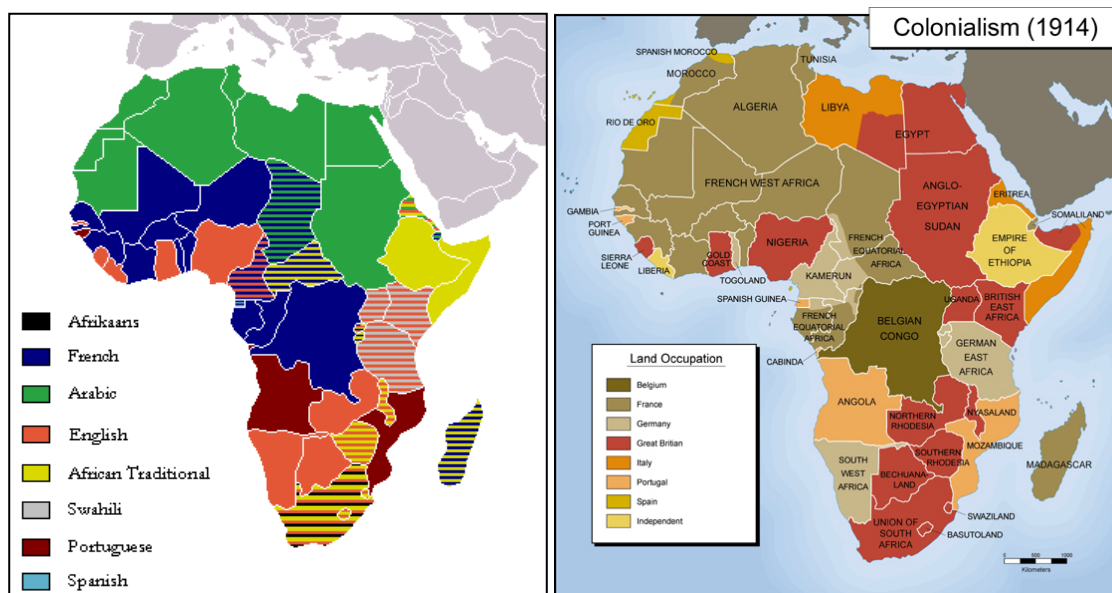
Figure 6: Official Languages in Africa (Africa, 2008) on left and Map of European colonies in Africa in 1914 (Exploring Africa, 2013) on right

Mali was a French colony prior to 1960 when it officially gained independence. Following independence, a dictatorship controlled the country. President Alpha Konare won the first two democratic presidential elections in 1992 and 1997. President Amadou Toumani Touré won the next two elections in 2002 and 2007 (CIA World Factbook, 2012). Given this history, it was generally considered to be a stable

democracy and a model to emulate for other African countries. However, dating back to its colonial days, Mali has had ethnic tension and conflict in its Northern provinces particularly due to Tuareg unrest (Lecocq, 2010).

The Tuareg historically have had a society based on a set of social strata into which one is born, including a lower slave class (Lecocq, 2010, p. 5). Baz Lecocq, in his book, *Disputed Desert,* classifies a Tuareg's status by considering if one is free or unfree, part of a strong or weak group, and if they have a prestigious lineage or not. While not always accurate, the slave class was traditionally perceived as 'black' and the noble class as 'white'. Even though France formally abolished slavery in 1905, the emancipation process is still not complete in some Tuareg societies (Lecocq, 2005). The legacy of slavery has fueled ethnic divisions in Northern Mali throughout history and continues to plague the relations between the 'white' Tuareg and the 'black' ethnic groups of other parts of Mali.

In 1960 when the Tuareg people of Mali were told by the French that their land would be controlled by the government in Bamako, there was immediate resistance. The first of three Tuareg rebellions was in response to being included in the state of Mali and happened between May 1963 and August 1964. This conflict, eventually won by the Malian government, resulted in many civilian Tuareg killings by government troops. The Tuareg, whose main leaders were arrested, eventually were persuaded to stop fighting, leading to a relative calm for many years (Lecocq, 2010).

The next major rebellion from 1990-1996 resulted in a time when Mali nationalism was at a high point, as democracy was taking shape in the country. The Tuareg were portrayed by the Mali government as nomad invaders and ethnic differences were highlighted and exploited. The Tuareg, fighting in the desert terrain, as they are accustomed, were militarily superior to the government troops leading to a compromised peace called the National Pact. This peace incorporated Tuareg into the military, a decreased presence of the Malian military in the north, provided tax exemptions to Northern inhabitants for ten years, and a special social economic and administrative status for the North (Lecocq, 2010, pp. 322-323). However, many of these agreements were slow to be implemented or were not implemented at all, leading to further discontent.

In May 2006, a Tuareg group called the Democratic Alliance for Change (ADC) rebelled against the Malian government calling for adherence to the National Pact, more autonomy for Northern Mali, and a more equitable distribution of resources (Miller, 2013). Iyad Ag Ghaly, the future leader of AAD, and Ibrahim Ag Bahanga were two of the major figures of this movement. Ag Ghaly and most of the Tuareg would agree to an Algerian mediated ceasefire while Ag Bahanga and a small group would continue to fight, eventually being exiled to Libya. In 2011 Ag Bahanga died in a car accident. His organization would eventually join the MNLA in their quest for an independent Azawad.

The most recent Tuareg rebellion, beginning in January 2012, initially resulted in large territorial gains by the Tuareg. Organized under the National Movement for the Liberation of Azawad (MNLA), the Tuareg took control of all of Northern Mali. The conditions for this rebellion were set up on a number of key factors. Previous agreements between the Tuareg and the Mali government were perceived by the Tuareg as broken promises. Additionally, following the fall of the Libyan dictator, Gaddafi, many Tuareg fighters who were employed by the Libyan military returned to Mali with large amounts of weapons. To add to the mixture, AQIM and other Islamic extremist groups that had been operating in the region for years were willing to assist the MNLA in armed resistance against the government. These organizations added money, weapons and fighters to an already powerful group. The Malian army, attempting to fight the rebellion, was poorly trained and equipped, and forced to deal with desertions of Tuareg and others to the opposing side. Feeling unsupported by the government, the Mali army Captain Amadou Sanogo organized a coup to depose President Touré. Following the coup, the government forces put up little resistance, allowing the MNLA, with assistance from extremist Islamic fighters, to gain control over large portions of Northern Mali. In April 2012, the MNLA issued a declaration of independence for Azawad. Shortly after independence, two Islamic extremist groups, Ansar Al-Din and MUJAO, began enforcing a strict interpretation of Shari'a law in areas they controlled. The MNLA, in favor of a more tolerant form of Islamic government, objected to imposing Shari'a law on the population. This led to disagreements between the MNLA and the Islamic extremist organizations. Battles began to take place

throughout Northern Mali with MNLA losing control of much of the territory to Ansar Al-Din and MUJAO (BBC News, 2012).

In early January 2013, Islamic extremist fighters began pushing further south into government held territory. The provisional Malian government, unable to stop the militants themselves, asked France for support. The French entered Mali on 11 January 2013. By early February all of the main cities of Northern Mali were regained by Malian, French and other forces. Other than France, the international ground forces are from African nations supported by the Economic Community of West African States (ECOWAS) and the operation is classified by the United Nations as the African-led International Support Mission in Mali (AFISMA). By the end of January 2013, 1,400 non-French AFISMA troops were supporting the mission in Mali from Nigeria, Benin, Togo, Senegal, Burkina Faso, and Chad (Nuland, 2013).

2.2.6   United States Efforts in the Region.

The Trans-Saharan Counterterrorism Partnership (TSCTP) is the U.S. government's program designed to provide support and training to governments in the Pan-Sahel (Mauritania, Mali, Chad, Burkina Faso, Niger, Nigeria, and Senegal) (Africom.mil, 2012). Additionally, TSCTP is designed to increase communication and counterterrorism efforts between the Pan-Sahel countries and Maghreb countries (Algeria, Morocco and Tunisia). The U.S. seeks to increase multinational support for counterterrorism principals within Africa by engaging the African Union and the Economic Community for West African States (ECOWAS). TSCTP replaced the smaller

scope of the Pan-Sahel Initiative (PSI) that took place from 2002 to 2005. TSCTP is a multifaceted approach led by the State Department that includes the U.S. Agency for International Development (USAID), Department of the Treasury, Federal Bureau of Investigation (FBI) and the Department of Defense (DoD). The DoD portion of TSCTP is called Operation Enduring Freedom – Trans Sahara (OEF-TS). OEF-TS focuses more on security and cooperation than on counterterrorism. In 2007, AFRICOM was established and has since assumed responsibility of the military portion of the TSCTP.

Bilateral support from the U.S. government is also given to countries within the Maghreb and Sahel region in the form of the Anti Terrorism Assistance (ATA) Program. In 2009, the U.S. spent over $500,000 to train Moroccan and Libyan police (CSIS, 2010, p. 6). "The Defense Department is also using '1206 funding' authorized in the 2006 National Defense Authorization Act by providing military equipment and hardware (CSIS, 2010, p. 6)." Additionally, the U.S. is participating in the NATO OPERATION ACTIVE ENDEAVER which is a naval operation designed to prevent smuggling between Africa and Europe.

The United States must prioritize its potential actions against AQIM in context with all other actions around the world. The actions of the United States within the Maghreb are just a small part of the actions conducted within Africa. There are terrorist threats all across Africa from the Maghreb to Nigeria, the Democratic Republic of Congo, Somalia, and Yemen (Al-Qa'ida in the Arabian Peninsula - AQAP). See Figure 7 for a map provided by the Washington Post on 13 June 2012 depicting their estimation of U.S.

military intelligence operations ongoing within Africa and the Arabian Peninsula
(Whitlock, 2012).
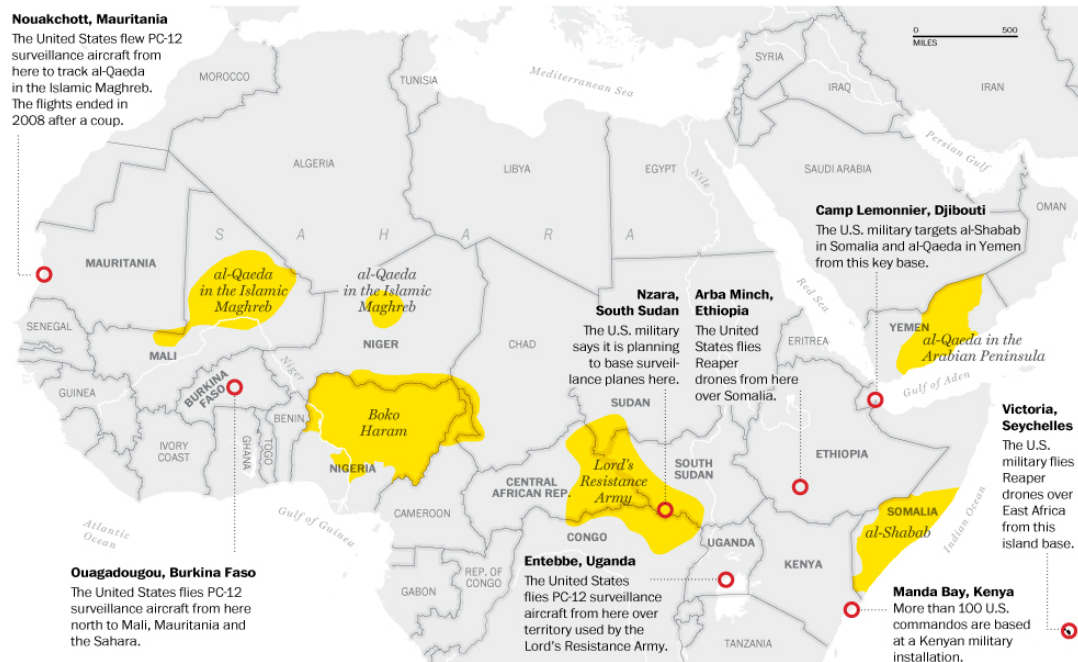
Figure 7: U.S. Military Intelligence Network within Africa (Whitlock, 2012)

The United States has supported and assisted in the French operations in Mali
through "refueling efforts, logistical movements, troop transport and information
sharing (Roulo, 2013)." From 21 January to 29 January 2013, the U.S. Air Force provided
airlift support primarily through C-17 Globemaster III sorties. Additionally, the U.S. KC-
135 Stratotanker supported French fighter aircraft with refueling missions (Roulo, 2013).
The United States has agreed to future airlift missions including providing support to
troops from African countries that have volunteered to assist in Mali. In addition, the
U.S. signed a status of forces agreement with Niger in January 2013 (Nuland, 2013) to
provide an opportunity for increased intelligence collection opportunities in the region.

2.3 Dark Social Networks

Given the historical background of AQIM and the conflict in Mali, as well as the United States' interests in eliminating the ability of terrorists to operate openly, there is an obvious need to gain a better understanding of the key actors participating in this conflict. Social network analysis methods can be used to analyze the key actor's relationships and make observations about the conflict as a whole. In recent years, social network analysis has become a popular and valuable tool for modeling and understanding networks of all kinds. Dark networks are illegal and covert networks such as terrorists, drug traffickers, and insurgencies (Raab & Milward, 2003). Since September 11, 2001, due to the War on Terror and increased grant money, researchers have gained an increased focus publishing many articles on social network analysis of terrorist organizations. Ressler (2006) outlines social network analysis contributions to dark networks. Krebs (2001) mapped the 9-11 terrorist network, Rodriguez (2005) modeled the 2004 Madrid train bombings, Sageman's book, *Understanding Terror Networks*, (2004) collected biographies on 172 Islamic terrorists from open sources to study terrorist networks around the world. Carley has multiple works: Dynamic *Network Analysis* (2003), *Estimating Vulnerabilities in Large Covert Networks* (2004), *Destabilization of Covert Networks* (2006), and *Locating Optimal Destabilization Strategies* (Moon & Carley, 2007) just to name a few. Walther and Christopoulos (2012) authored an excellent SNA of individuals involved in the current Mali rebellion based on

names gathered in French newspapers. No other previous work has been found by the author that has attempted to analyze signed dark social networks.

2.4   Graph Theory and Social Network Analysis

Graph theory provides social network analysts the vocabulary, mathematical operations and theorems to model networks (Wasserman & Faust, 1994, p. 93). Graphs have been widely used in SNA to represent social relations since Moreno (1934) published graphical depictions of social networks in his seminal work: *Who Shall Survive? Foundations of Sociometry, Group Psychotherapy and Sociodrama*. A graph, *G* = (*N, E*), is made up of a set *nodes, N*, representing *n* actors within a network, and a set of *edges,* E, representing *m* ties or relationships between two actors (Wasserman & Faust, 1994, p. 72).   There are *n* nodes and *m* arcs within a graph. In Figure 8, *G* = (*N, E*) where *N* = {A, B, C, D} and *E* equals the relationships {a, b, c, d, e} or {A-C, A-B, A-D, B-D, C-D}. In this case *n* = 4 and *m* = 5.
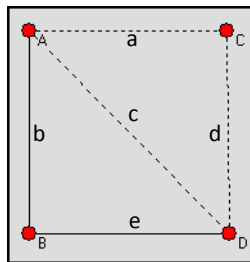
Figure 8: A notional network with solid lines representing positive relationships and dotted lines representing negative relationships.
Graph by author using Pajek (Batagelj & Mrvar, 1996)

Actors or graphical nodes are the basis for SNA. An actor can be an individual or a group of individuals that may or may not have ties to another actor (individual or

group). Actors that have ties or relations to other actors are shown graphically by

drawing a line between the two nodes. Relations can be either directed or undirected.

More simple social networks consist of undirected ties, meaning that the relationship

between the two actors is given and received by both actors. This type of relationship is

symmetric (i,j) = (j,i). The network in Figure 8 has undirected ties making it symmetric.

In a directed relationship, one actor influences the other actor, but the relationship may

or may not be reciprocated. This type of relationship is graphically depicted with an

arrow instead of just a line. Directed relationships are shown visually in a directional

graph or *digraph*. Within a digraph arrows point towards the actor that is receiving

influence.

A *walk* is "a sequence of nodes and lines, starting and ending with nodes, in

which each node is incident with the lines following and preceding it in the sequence"

(Wasserman & Faust, 1994, p. 105). The length of a walk is the sum of the lengths of all

of the arcs of the walk. A walk from node A to node D is A-C-D with a length of two or A-

D with a length of one, assuming each arc is a length of one. A cycle is a walk of at least

three nodes that begins and ends at the same node, all lines are unique, and all nodes

(other than the start/end node) are unique (Wasserman & Faust, 1994, p. 108). The

cycles in Figure 8 are A-B-D-A, A-C-D-A, and A-C-D-B-A.

Social networks are mathematically depicted by using matrices. If actor *i* is

influencing actor *j*, then the (i, j) cell of the matrix will have a value representing the

strength of that influence. If actor *i* has no relationship with actor *j*, then cell (i, j) will

have the value of zero. In an *n* by *n* matrix, called an adjacency matrix, each cell (1, 1) to

(*n, n*) is populated with a value representing the relationship between *i* and *j*. Each of

the values on the diagonal (1, 1) to (*n, n*) are zero because only external relationships

are considered. The adjacency matrix is used to calculate measures and draw

conclusions on the significance of different actors within the network based on their

connections. The signed adjacency matrix, an adjacency matrix that has signed values,

is symmetric when non-directional relationships exist within a network. When

directional relationships exist, the matrix becomes asymmetric. When actor *i* has a

relationship with actor *j*, but actor *j* does not have a relationship with actor *i*, then there

is a value in cell (*i, j*) of the signed adjacency matrix and a 0 in cell (*j, i*). This type of

relationship may exist when actors are in different spheres of influence (such as a leader

and follower, where the leader does not know the follower well, but the follower is

influenced by the leader).

	A	B	C	D
A		1	-1	-1
B	1			1
C	-1			-1
D	-1	1	-1	

Figure 9: A matrix representation of the graph in Figure 8

In a signed matrix, where a relationship can be positive, negative or null, a value

of one in cell (*i, j*) depicts a positive relationship from *i* to *j*, a negative one represents a

negative relationship from *i* to *j* and a zero shows no relationship exists. Figure 9

displays the matrix form of the network from Figure 8.

Most algorithms and other sources of Social Network Analysis are designed for binary data. Other scales of measurement that exist are Multiple Category Nominal, Grouped Ordinal, Full Rank Ordinal and Interval. The Multiple Category Nominal measurement is used when different types of relations are measured. In this case if no relation exists then a zero would still be used, but a one, two or other number could represent other relations. These numbers represent categories not numerical values, therefore category two is not necessarily twice as important as category one. Multiple Category Nominal data can be converted into binary data for each type of relationship or to depict if a relationship exists or does not exist.

Grouped Ordinal data uses the binary numbers, but also allows for a -1 value if a negative relationship exists. Full Rank Ordinal measurement ranks the actors from 1 to *n*. This scale indicates that one is more important than two and two is more important than three, but not necessarily at the same proportion. The Interval scale is similar to the Full Rank Ordinal Scale except that the interval scale maintains the strength of tie (Hanneman, 2005).

As previously stated, binary data is most commonly used and widely applied type of data in SNA. SNA metrics are most often defined for use with binary data. However, when more data is available, analysts can use this data for increased understanding of the intricacies of the network. Table 3 shows the different scales of measurement that are used to mathematically represent data. Chapter One of Hanneman's book *Introduction to Social Network Methods* outlines different scales of measurement often

used in social networks. In order to evaluate signed networks, Grouped Ordinal data are primarily used in this thesis. Whatever scale is used, however, it is assumed that a valid method to develop such data has been utilized. Care must be taken to assure this assumption is valid.

Table 3: Scales of Measurement (Hanneman, 2005)

Binary	0 = No Relationship; 1 = Relationship
Multiple Category Nominal	0 = No Relationship; 1,2,3, etc = different types of relationships
Grouped Ordinal	0 = No Relationship; 1 = Positive Relationship; -1 = Negative Relationship
Full Rank Ordinal	Actors ranked in order from 1 to n (where n = # of actors); 1 is more important than 2, but no strength of tie can be inferred
Interval	Actors ranked in order and scaled according to the strength of the tie (1 is 2 times as important as 2)

2.5   Structural Balance Theory

Fritz Heider, an Austrian psychologist, first developed the idea of balance theory in *Attitudes and Cognitive Organization* (1946). Heider's cognitive balance theory observes how positive and negative relationships coexist within social situations. Examples of positive relationships are: friends, like, love, or trust. A negative relationship is the opposite of the positive (i.e. enemies, dislike, hate, or distrust). Heider evaluates the relationships between two actors and three actors and defines balance. Heider's theory is best described by quoting his paper:

> In the case of two entities, a balanced state exists if the relation between them is positive (or negative) in all respects…. In the case of three entities, a balanced state exists if all three relations are positive in all respects, or if two are negative and one positive.(1946, p. 110)

When observing a relationship between two actors (a dyad), there is balance only when both parties like or dislike each other. Tension is observed in a relationship where one party likes the other, but is disliked by the other. According to Heider, this creates an unbalanced relationship and is calculated by multiplying the signs of the relationship. Two positive relationships (+)·(+)=(+) and two negative relationships (-)·(-)=(+) both result in a balanced (positive) relationship. Whereas a (+)·(-) or (-)·(+) both result in an unbalanced (negative) relationship.

When observing three actors (a triple or triad), eight different possibilities exist in an undirected network (the relationship of *i* to *j* equals the relationship of *j* to *i*). The eight possibilities are presented in Figure 10. Heider referred to the three parts of a triple as P for the person, O for other and X for another entity or object. Throughout this thesis, *i, j* and *k* are used as the three nodes of the triad; all of them represent individuals (or groups of individuals). For simplicity, throughout the thesis the term like (dislike) is used to describe a positive (negative) relationship.
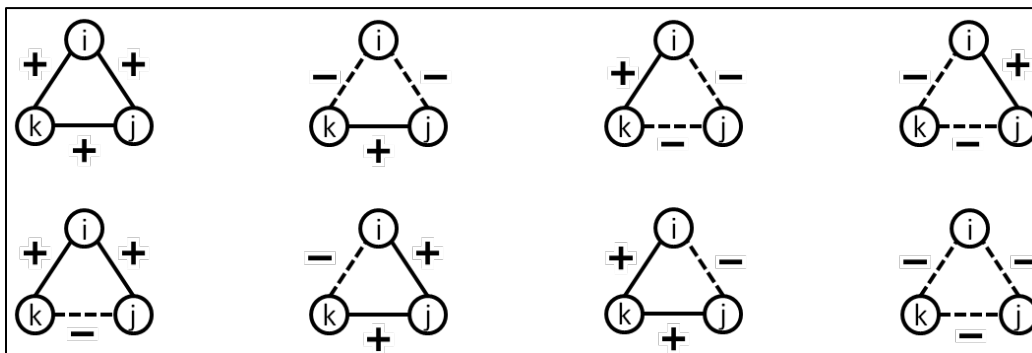
Figure 10: The eight possible triples that can exist in an undirected network. Adopted from (Wasserman & Faust, 1994, p. 224)

The top row of Figure 10 consists of balanced triples. A triple is balanced if the

product of the cycle (a sequence of nodes and lines that are each distinct except for

having the same starting and ending node) in each triple is positive. A triple with three

positives or one positive and two negatives is balanced. If a triple has all positive

relationships, then there is balance because everyone likes each other resulting in

minimal tension. When there are two negative relations and a positive relation, there is

balance because the two actors that like each other dislike the third actor and the third

actor dislikes both other actors. The bottom row of Figure 10 consists of unbalanced

triples. This is easily identified because the product of the cycle of the three

relationships (two positives and a negative and three negatives) results in a negative

value. Heider's presentation suggested an explanation on what would happen within an

unbalanced triple:

> If no balanced state exists, then forces towards this state will
> arise. Either the dynamic characters will change, or the unit relations will
> be changed through action or through cognitive reorganization. If a
> change is not possible, the state of imbalance will produce tension.
> (1946, pp. 107-108)

 If one actor likes the other two, but they do not like each other, there is tension within

the group. It is likely that enough stress will be put on the relationships to cause one of

them to change in either of two ways. The negative relationship could turn positive

resulting in three positive relationships and balance. The other option is that the actor

with two positive relations may have to choose which friend it likes better and team

with that friend against the third. This action would result in two negatives and a

positive, putting the triple into a balanced state. In the case where all three actors dislike each other, instability occurs and over time it is likely that two actors will join against the third actor resulting in a balanced triple.

Harary (1953) and Cartwright and Harary (1956) expanded the structural balance concept using graph theory to mathematically explain Heider's concepts. Cartwright and Harary (1956) enabled Heider's concepts to be applied to units containing more than three entities. Building on the concept of a triple being balanced if the product of the cycle is positive, Cartwright and Harary defined a signed graph as being balanced if all of its cycles are balanced. The example in Figure 11, taken from Cartwright and Harary (1956), demonstrates how the seven cycles in graphs a and b are all positive, making those graphs balanced. Graphs c and d are not balanced because they contain at least one cycle that is negative, for example the cycles h-j-k-h in graphs c and d are negative (as are other cycles).
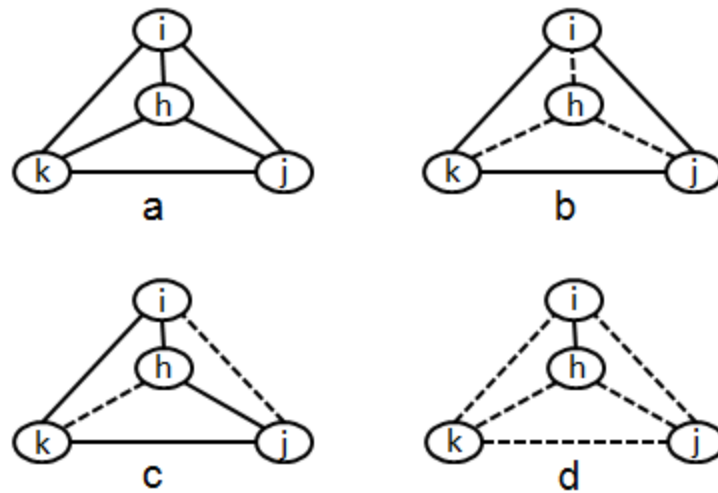
Figure 11: Four signed graphs containing four points and six lines each. Structures a and b are balanced but c and d are not balanced (Cartwright & Harary, 1956, p. 284). Dashed lines represent negative relations and solid lines represent positive relations.

Balance theory is widely applicable to many areas of social science. It has been applied to international relations (Harary, 1961)(Moore, 1978), consumer behavior (Woodside, 2001), (Russell & Stern, 2006), (Roy, Gammoh, & Koh, 2012), and supply chain and logistics (Carson, Carson, Knouse, & Roe, 1997) to cite a few. As more signed social network data has become available in recent years, analysis has been conducted using large signed data sets from Epinions, Slashdot Zoo, Wikipedia and other websites to evaluate and predict signed relations. Guha *et al.* (2004) were the first to develop an approval of balance theory to evaluate a person's trust/distrust relationships and predict whether he will trust/distrust others in the network. This propagation of trust creates a wider trust network through the notion that the friend of my friend is also my friend, the friend of my enemy is my enemy, the enemy of my friend is my enemy, and

the enemy of my enemy is my friend. The literature review in Section 2.8 provides a

detailed list of sources where balance theory is used to evaluate signed network data.

2.6   Subsets within a Signed Network

2.6.1   Two Subsets in a Balanced Signed Graph.

If all cycles within the graph need to be identified and calculated to determine

structural balance, then large graphs can quickly become computationally challenging

problems. For this reason, it may be easier to determine if a graph is balanced through

other methods. Cartwright and Harary also defined a signed graph as being balanced "if

and only if all paths joining the same pair of points have the same sign" and "if its points

can be separated into two mutually exclusive subsets such that each positive line joins

two points of the same subset and each negative line joins points from different subsets

(Cartwright & Harary, 1956, p. 286)." Using this method, a balanced graph can be

partitioned into two subsets allowing for an easier determination if the graph is

balanced or not. See Figure 11b for an example of a balanced graph that is divided into

two mutually exclusive subsets (i,j,k is one and h is the other). It should be noted that

sometimes one of the subsets of a balanced graph is empty, as is the case of the graph

in Figure 11a. Additionally, a visual inspection of a balanced graph may not be as

obviously balanced as the example in Figure 11b.

2.6.2   Identifying More than Two Subsets of a Signed Graph.

Davis (1967) built on Cartwright and Harary's observations that a balanced graph can be split into two subsets after observing that in reality signed graphs could often be split into more than two subsets. Davis defined a clustering as two or more subsets of a signed graph. He then proved that for any signed graph S, "S has a clustering if and only if S contains no cycle having exactly one negative line (Davis, 1967, p. 181)." Additionally, "two points are in the same subset if and only if they are joined by an all-positive path (Davis, 1967, p. 182)." For example in Figure 11 graphs a, b and d, there are no cycles with exactly one negative line. Therefore, these graphs are balanced and can be divided into subsets. To determine the subsets, search for positive paths between points. The only positive path in graph b is i-j-k-i therefore i, j, and k are in one subset and h is in another. Graphs a and d are both examples where one of the subsets are empty. Graph c cannot be divided into subsets because it has at least one cycle with one negative line (i-h-j-i or k-h-j-k). If a graph, when divided into k subsets, is balanced, then it is said to be k-balanced or a weakly balanced network. Graph d is 3-balanced because i and h are in one subset and j and k are each in their own subset. Nodes i and h are determined to be in the same subset because they have a positive connection.

Unfortunately, when working with real data, networks are rarely perfectly balanced and therefore are unable to be neatly divided into subsets. To account for this, other methods for clustering groups of actors into subsets with similar characteristics are required. The general clustering problem is an optimization problem

to partition a graph **C** into sub units **C** = {C_1, C_2, ..., C_k} where the minimum distance is found between clusters. The farther the distance between two clusters, the bigger the difference between the groups. Groups that have a small distance between them are more closely related than groups that are farther away. Distance can be measured in many different ways, but common methods are variations of the Minkowski distance (the Manhattan, Euclidean, and Chebyshev) and Mahalanobis distance measures. These methods use different mathematical techniques to calculate between the centers of clusters C_i and C_j. There is a large amount of literature dedicated to the field of cluster analysis and there are many heuristics and algorithms used to partition data into like groups. The two most common methods of clustering are partitioning and hierarchical. These methods are introduced in the following two sections. A review of clustering techniques of weakly balanced networks in the literature is discussed in section 2.8.

2.6.2.1 *Partitioning Methods.*

A partitioning method constructs *k* clusters, or subsets, from the nodes. The analyst may know that the nodes need to be divided into *k* number of subsets or multiple *k* can be found to find the most optimal solution. Each subset must contain at least one actor and each actor can only belong to one subset (Kaufman & Rousseeuw, 1990, p. 38). Due to these constraints, the number of subsets must be less than or equal to the number of actors, $k \leq n$. The difficulty with clustering via the partitioning method is that the number of partitions is equal to the second-order Stirling number shown in Equation 1 (Doreian, Batagelj, & Ferligoj, 2005, p. 135):

$$S(n,k) = \frac{1}{k!}\sum_{i=0}^{k}(-1)^{k-i}\binom{k}{i}i^n$$

<div align="right">Equation 1</div>

As *n* and *k* increase, the number of possible partitions becomes very large. Therefore, enumeration of all possible options where *k* is large (generally greater than 12) becomes a computationally difficult problem.

2.6.2.2 Hierarchical Methods.

Hierarchical algorithms conduct a series of partitions in a graph from *k*=1 (all actors in one group) to *k*=n (all actors form their own groups). The algorithm steps through the process by dividing the graph into two groups. It next divides one of those two groups into another group, forming three groups. The approach then takes one of the three groups and splits it. It continues until all actors are completely partitioned from each other. Some hierarchical algorithms work in the opposite sequence, starting with a completely segmented group and systematically grouping actors together. This type of clustering does not allow for corrections to be made. For example, no group can be split up if they are put together in a previous step, even if it would result in a better clustering. This allows hierarchical methods to be computationally much quicker than partitioning methods, but can limit the accuracy of the clusters (Kaufman & Rousseeuw, 1990, p. 45).

2.6.3 Blockmodeling.

"Blockmodeling is best viewed as a set of general tools for clustering social actors and social relations in meaningful ways (Doreian, Batagelj, & Ferligoj, 2005, p. 131)."

Models that simplify and explain a complex network without losing important information are valuable. A blockmodel provides this capability by presenting a network in a way that highlights the positions and roles of the actors within the network. Blockmodels were first developed by White, Boorman and Breiger (1976). Blockmodels consist of a partition of actors in the network into discrete subsets (positions). Each position has a unique relationship to each other position within the network (Wasserman & Faust, 1994, p. 395).

2.6.3.1 Blockmodeling Displays.

A blockmodel can be displayed many ways; by a reduced graph, by a matrix, or by an image matrix (Doreian, Batagelj, & Ferligoj, 2005, p. 169). A reduced graph combines each subset of actors into a node and redraws the graph using the condensed number of nodes. This presents a less cluttered illustration of the dynamics between the different subsets within the network. See Figure 12 for the reduced graph of Figure 11b.
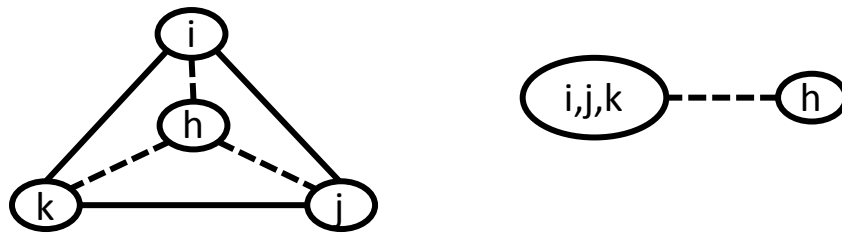
Figure 12: Figure 11b on the left and its reduced graph on the right. The reduced graph combines three nodes with the same relationships into one node, making the graph less complex. Dashed lines represent negative relations and solid lines represent positive relations.

A matrix can be used to show a blockmodel by rearranging the signed adjacency matrix so that subsets of similar actors are grouped together along both axes of the matrix. Once similar actors are grouped, lines dividing the subsets are drawn in both the horizontal and vertical directions. This delineates the relationships of the subsets into blocks. Each block represents how the two groups relate. If there are all ones and zeros in a block (positive block), then the subgroups in that row/column have all positive (or null) relations. If there are all negative ones and zeros in a block (negative block) then the subgroups in that row/column have all negative (or null) relations. If there are all zeros in a block, then there is no relation between the subgroups in the rows/columns of that block. A blockmodel of a balanced signed network consists of positive blocks on the diagonal blocks and negative blocks off the diagonal (Ferligoj, Doreian, & Batagelj, 2011, p. 438).

	h	i	j	k
h		-1	-1	-1
i	-1		1	1
j	-1	1		1
k	-1	1	1	
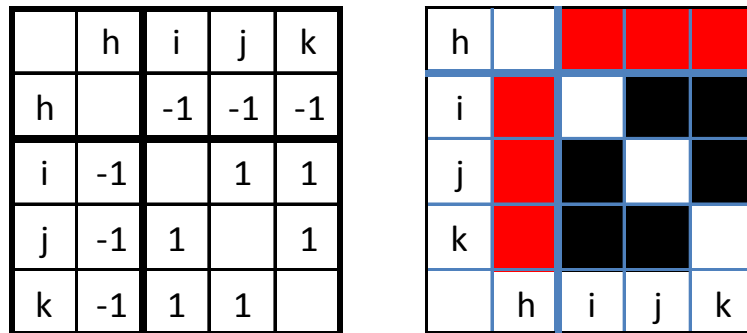
Figure 13: The matrix representing the network in Figure 12 is on the left and the image matrix on the same network is on the right. The matrices have lines separating the blocks and displaying the two subsets within the network.

An image matrix displays a blockmodel in a similar way that a matrix does. The difference is that the image matrix does not use zeros, ones and negative ones. The

image matrix uses colors (black for positive, red for negative, and white for zero is commonly used in grouped ordinal data) or images (often X's, O's and blank to represent ones, negative ones, and zeros respectively). The image matrix allows for the analyst to visually detect where inconsistencies exist easier than in a normal matrix.

2.6.3.2   Conventional Blockmodeling.

Conventional blockmodeling partitions actors based on the structural or regular equivalence of the actors. Two actors are structurally equivalent if they are connected exactly the same way to other actors in a network. Regular equivalence is a more general form of structural equivalence grouping actors that are in the same hierarchy. A formal definition for both can be found in *Generalized Blockmodeling*(Doreian, Batagelj, & Ferligoj, 2005, p. 172). Structurally equivalent actors can be grouped together within the signed adjacency matrix. The set of relations from actors in group C_i to all actors in C_j forms a *block*. Given k different clusters, the matrix can be sectioned into k^2 blocks. There are $k(k-1)$ off diagonal blocks which contain ties between blocks (Ferligoj, Doreian, & Batagelj, 2011).   Conventional blockmodeling converts network data into (dis)similarity matrices that are then clustered based on structural equivalence using one of the many clustering algorithms.

2.6.3.3   Generalized Blockmodeling.

Doreian *et. al.* (2005) developed generalized blockmodeling to work directly with the data (instead of transforming it), loosen the restrictions on conventional

blockmodeling allowing for more block types, and use a criterion function to measure the fit of the data (Doreian, Batagelj, & Ferligoj, 2005, pp. 25-26). Since generalized blockmodeling works directly with the data, it does not have to compute (dis)similarity matrices which sometimes do not equate the data well in terms of structural equivalence. Furthermore, in using a criterion function, generalized blockmodeling allows for a measure for how well the blockmodel fits the data. This is beneficial in evaluating and comparing different blockmodels. See Chapter Six of *Generalized Blockmodeling* (Doreian, Batagelj, & Ferligoj, 2005) for more information on the differences between conventional and generalized blockmodeling.

2.6.3.4 Relaxed Blockmodeling.

Doreian and Mrvar (2009) outline a more wide-ranging approach to signed generalized blockmodeling through *relaxed blockmodeling,* allowing for both positive and negative blocks to appear anywhere on the blockmodel. Generalized blockmodeling allows positive blocks only on the diagonal and negative blocks only off the diagonal. The relaxed approach is based on the theory that there are other forces outside of structural balance theory that contribute to the clustering of actors within a network. This approach still allows for structural balance theory (by letting positive blocks still appear on the diagonal and negative blocks off the diagonal), but also allows other options. For example, in real world networks, some actors (particularly mediators) are universally liked, despite the division of actors predicted by social balance theory. Some of the relationships of these actors would be categorized as

inconsistent in generalized blockmodeling, but would be allowed in relaxed

blockmodeling. "Differential popularity, differential receipt of negative ties, mediation

blocks and actors with mutual negative ties can all be identified (Doreian & Mrvar,

2009)" through Relaxed Blockmodeling.

2.7 Measuring Imbalance in Signed Networks

Since most signed networks are not exactly k-balanced, it is necessary to

measure how imbalanced a signed network is when divided into k partitions. Cartwright

and Harary determined that the degree of balance of a signed graph is the "ratio of the

number of positive cycles to the total number of cycles (Cartwright & Harary, 1956, p.

288)." If G is a signed graph, then b(G) is the degree of balance of G and is calculated in

Equation 2.

$$b(G) = \frac{\#\ positive\ \text{cycles}}{\#total\ \text{cycles}}$$
Equation 2

Since the number of positive cycles can go from zero to the total number of cycles, *b(G)*

can vary between zero and one. If *b(G)* is equal to one, then the graph is balanced. One

must take into account the structure of the signed graph in evaluating the value of *b(G)*.

In Figure 11, the balance of graphs a and b are *b*(a) = *b*(b) = 7/7 = 1, since there are

seven balanced cycles and seven total cycles in each graph. This indicates both a and b

are balanced graphs. In graph c, *b*(c) = 5/7, since there are five positive cycles and two

negative cycles. In graph d, *b*(d) = 3/7 because three positive cycles (i-j-h-i, i-h-k-i, and i-

j-h-k-i) are in the graph. Therefore graphs c and d are both unbalanced, but graph c is

more balanced than graph d. This ratio provides a method to measure imbalance in a network, but requires that all cycles be tested for balance. Testing all cycles can be a lengthy process depending on the size of the network.

Harary (1959) defined an additional way to measure imbalance by calculating the number of ties that need to be removed in order for the network to come into balance. This deletion-minimal set is equal to the negation-minimal set, the number of ties whose signs must be changed for the network to come into balance (Harary, Norman, & Cartwright, 1965, p. 350). Doreian and Mrvar (2009) created an algorithm to calculate this second type of measurement as well as a partitioning procedure for signed networks. Their algorithm calls for the calculation of all of the negative ties within subsets and the positive ties between subsets. These two types of relations are inconsistent with a balanced network and therefore need to be negated or deleted, according to the second method of calculating imbalance, in order for the network to become balanced. If a blockmodel does not fit the data perfectly, then there will be inconsistencies within the blockmodel. Inconsistencies are defined as instances in which an empirical blockmodel is inconsistent with the specified blockmodel (Doreian, Batagelj, & Ferligoj, 2005, p. 23). These inconsistencies can be used to determine how well the data and the blockmodel fit using a criterion function.

2.8   Partitioning Signed Networks

A number of different techniques to determine clusters or communities within weakly balanced signed networks (also known as *k*-balanced networks, see section

2.6.2) have been recently developed. Doreian and Mrvar, in a 1996 article, present a local search strategy, starting with a random partition into k sets and moving to neighbor states to find the local optimal value of the criterion function. This method is discussed in more detail in section 2.8.1 and is the primary method used in this thesis. In Chapter 10 of their book, *Generalized Blockmodeling* (2005), Doreian, Batagelj, & Ferligoj expound on the techniques and provide many examples from common SNA datasets. The most relevant example to this thesis is the analysis of Read's cultural data on the tribes in the Central Highlands of New Guinea (Read, 1954) in which they partitioned the network of tribes and identified a specific tribe that had unique relationships.

The following are other examples in the literature that draw on structural balance principles to cluster actors within a network using various mathematical techniques. Yang, Cheung, & Liu (2007) developed an agent-based heuristic to conduct a random walk on a signed graph to determine which community a node belongs. Bansal, Blum, & Chawla (2004) and Demaine, Emanuel, Fiat, & Immorlica (2006) used approximation algorithms to conduct correlation clustering on signed graphs to minimize the disagreements and maximize the agreements between groups. Kunegis, Lommatzsch, & Bauckhage (2009) analyzed the social network Slashdot Zoo using a clustering coefficient to evaluate the global network characteristics, centrality and popularity measures to evaluate node characteristics, and distance and similarity measures to evaluate link characteristics. Kunegis, Schmidt, Lommatzsch, Lerner, De

Luca, & Albayrak (2010) use the spectral clustering algorithm to identify the top k eigenvetors of the signed graph Laplacian and run the k-means algorithm to calculate the clusters. Chiang, Whang, & Dhillon (2012) extend this work to better apply to the k-way clustering problem when k is greater than two. Hsieh, Chiang, & Dhillon (2012) use matrix completion methods to fill in unknown relations within a network and then use a spectral clustering algorithm to determine the groups. Anchuri & Magdon-Ismail (2012) propose a two step spectral approach to iteratively optimize modularity and frustration.

2.8.1 Relocation Method.

Doreian and Mrvar (1996) developed a local search heuristic to determine the best clustering option for network data called the relocation method. This method uses a criterion function to determine how well a blockmodel fits the data. The criterion function is then minimized to determine the local minimal optimum. The criterion function is defined as:

$$P(\boldsymbol{C}^*) = \min_{C \epsilon \Phi} P(\boldsymbol{C}) \qquad \text{Equation 3}$$

where **C** is a clustering of a given set of units U, Φ is the set of all possible clusters, and $P{:}\Phi{\rightarrow}\mathbf{R}$ is the criterion function:

$$P(\boldsymbol{C}) \;=\; N + P \qquad \text{Equation 4}$$

where N is the number of negative ties within subsets and P is the number of positive ties between subsets. A more general criterion function that allows the analyst to weight positive or negative inconsistencies differently is:

$$P(\boldsymbol{C}) = \alpha N + (1 - \alpha)P \qquad\qquad \text{Equation 5}$$

where $0 \le \alpha \le 1$. If $\alpha = 0.5$, N is weighted the same as P and Equation 5 is the same as

Equation 4. If $\alpha < 0.5$, then positive inconsistencies are weighted more. If $\alpha > 0.5$, then

negative inconsistencies are more highly weighted. The calculations in this thesis are

conducted with $\alpha = 0.5$ because little research has been conducted on the effects or

reasons to weight one type of inconsistency higher than the other. However, if such

knowledge exists for a given group of interest, α could be varied to correspond to

mission objectives.

In order to identify the least amount of inconsistencies, the criterion function

must be minimized. Doreian and Mrvar recommend using the relocation method to

locate the local optimum. Since this solution only finds the locally best solution and not

the global optimum, the procedure must be repeated a large number of times to ensure

that different initial clusters are used to gain confidence that the minimum solution to

the criterion function is the actual global optimum. The relocation method first

defined by Doreian, Batagelj, and Ferligoj in *Generalized Blockmodeling* (2005, p. 150)

and clarified by Brusco, Doreian, Mrvar, and Steinley (2011):

1. Select a value of k.

2. Randomly determine an initial clustering, C, with k clusters.

3. Repeat: If, in the neighborhood of the current clustering C, there exists a clustering C' such that P(C') < P(C), then move to C'. The neighborhood of a clustering C is determined by two transformations:

      (a) moving a vertex from one cluster to another cluster and

      (b) interchanging two nodes between different clusters. This process is repeated many times (in the order of many thousands) to minimize the risk of reaching only a local minimum rather than a global minimum.

4. Repeat the whole procedure for different values of k.

2.8.1.1 *Partitioning Weakly Balanced Networks.*

In order to identify if a network is weakly balanced (k-balanced), the criterion function needs to be tested for all values of k. When the Doreian/Mrvar algorithm determines that P(**C**) = 0 when C_k is tested, then a network is weakly balanced at k. Since there are no inconsistencies when clustered into k subgroups, the network is k-balanced. If inconsistencies exist for all k where $0 \leq k \leq n$ (n = total number of nodes), then the network is not k-balanced.

2.8.1.2 *Partitioning Imbalanced Networks.*

In reality, most signed networks are not k-balanced. In non-k-balanced networks, the criterion function will be greater than zero for all k. To find the best partition of an imbalanced network, the lowest value of the criterion function is found. Doreian, Batagelj, and Ferligoj (2005, p. 305) prove that in all signed networks, there will be a unique lowest value for the criterion function. This value will occur for partitions

with a single number of subgroups or for adjacent partitions in generalized

blockmodeling. For example, the criterion function will decrease as increasing values of

k are tested. The criterion function will reach a minimum and then begin to increase.

The minimum value could be at one or a series of multiple k's. However, in relaxed

blockmodeling, the criterion function decreases as k increases (Doreian & Mrvar, 2009).

The relocation method is easy to use and has a fast computational time, but does not

guarantee to find the optimal solution because it uses a local instead of a global search.

The risk of finding a non-optimal solution can be mitigated by conducting the local

search many times from different partitionings.

Brusco, Doreian, Mrvar, and Steinley (2011) present a branch-and bound

approach to address the problems with the relocation method, such as it may not find

the optimal global partition or all the optimal partitions. While the branch-and-bound

method does produce an optimal solution, in large problems it can result in long

computation times. The relocation method can produce optimal or near optimal

solutions (likely optimal, but undemonstrated in networks of $k>30$) in any size network

with minimal computational difficulty (Brusco, Doreian, Mrvar, & Steinley, 2011).

2.9 Social Network Analysis Metrics of Signed Networks

Section 2.7 demonstrated how to measure how balanced a signed network is by

taking a ratio of the positive cycles over the total number of cycles or by measuring the

minimum inconsistencies in a network. While these methods are good when comparing

networks or evaluating the whole network, often analysts are more interested in what

roles individual actors are playing within the network. The Social Network Analysis

metrics discussed in this section provide a way to assess individual actors within a

network.

2.9.1   Centrality.

There are many centrality measures that are common within SNA, Wasserman

and Faust (1994) provide a good explanation in Chapter Five of their book. However,

most centrality measures are not applicable to signed networks because, depending on

the formula, calculations with negative numbers can give erroneous results.   When not

applicable to signed networks, the measures can usually be applied to the unsigned

adjacency matrix (by taking the absolute value) or to an adjusted matrix that considers

just positive relations. However, care must be taken to ensure that applying centrality

to these different matrices is justified. If applied haphazardly, centrality metrics will not

provide the analyst with meaningful results. Eigenvector centrality and likes minus

dislikes are two possible methods for determining the centrality or prestige within

signed networks. Kunegis *et al.* (2009) identify additional popularity and centrality

measures that can be used to evaluate signed social networks. However, many of them

are highly correlated.

2.9.1.1 Degree Centrality.

In any network, the degree of a node n, d(n), is the measurement of how many

connections actor n has. It is calculated by summing the ties an actor has to other actors

or by summing the row or column of the adjacency matrix (Wasserman & Faust, p. 163).

Since a directed network has a direction for the flow of influence it contains indegrees and outdegrees. An indegree is calculated by summing the number of ties coming from other actors or by summing the number of 1's in the column of the adjacency matrix. Likewise, an outdegree is calculated by summing the number of ties going from an actor to all actors it influences or by summing the number of 1's in the row of the adjacency matrix (Wasserman & Faust, p. 126). The degree of an actor in a network can be an indication to how central that actor is to the network. In general, the higher the degree, the more connected the actor is within the network. Sometimes, as is the case in dark social networks, an actor with high degree centrality may not tell the whole story. For example someone with high degree centrality could be a highly influential actor, a messenger that has contact with a larger percentage of actors, or simply someone that practices poor operational security. Assessing the degree of an actor in a signed network can be done several ways. One can calculate the positive degree, the negative degree, or the positive minus the negative degree of actors within the network. The positive degree will tell how many friends an actor has. The negative degree will tell how many enemies an actor has and the positive minus the negative will tell if the actor has more friends than enemies within the network. Additionally, the ratio of positive (or negative) degree over the total degree (both positive and negative) will denote the proportion of friends (enemies) the actor has within the network. The ratio measure provides a better indication of how popular an actor is based on the relations that he or she has. This makes the ratio measure a potentially preferable approach to use in sparse networks than the positive minus negative measure.

2.9.1.2   Eigenvector Centrality.

Eigenvector Centrality is a measure of how central an actor is to the network

based both on how many connections the actor has and the influence of connected

actors. This measurement attempts to measure both the number of connections as well

as how important the connections are. The most common way to measure eigenvector

centrality was developed by Bonacich (1972) and is given in Equation 6. This equation

provides the centrality of the actor, *x*, by using the largest eigenvalue, *λ*, of a symmetric

adjacency matrix, *A*.

$$x = \frac{1}{\lambda} Ax$$ Equation 6

Bonacich and Loyd (2004) show eigenvector centrality can be used to examine

the impacts of both positive and negative relationships on status. Eigenvector centrality

when applied to signed networks can increase the status of a node by having a positive

connection to a high status node or a negative connection to a low status node. It can

also decrease the status of a node by having a negative connection to a high status node

or a positive connection to a low status node. Unfortunately, eigenvector centrality can

only be used with non-directional data because a symmetric adjacency matrix is needed

to ensure a positive eigenvalue (Bonacich & Lloyd, 2004).

2.9.1.3   Betweenness Centrality.

Betweenness Centrality measures how central an actor is to the network by

measuring its connection between other actors. If an actor is between two actors, then

it can influence the communication between the actors it connects. Freeman (1977, p. 37) defined g_{jk} as the number of geodesics, or arcs, linking n_j and n_k. He defined $g_{jk}(n_i)$ is the number of geodesics linking n_j and n_k that contain n_i. With the assumption that all geodesics are equally likely to be chosen for the path linking n_j and n_k, Freeman accurately quantified the betweenness centrality with Equation 7. Betweenness centrality can only be used on nonnegative edge weights. Applying it to the unsigned adjacency matrix is possible, but provides little insight. Since positive relations connect friends, the betweenness centrality should only be used to evaluate the positive relations of the network. However, this does not take into account negative relations and therefore disregards potential meaningful data within the network.

Equation 7

$$C_B(n_i) = \sum_{j<k} g_{jk}(n_i)/g_{jk}$$

2.9.2 Prestige.

Many different Social Network Analysts have used different terms to describe the importance of actors within the network. Centrality is a widely used term, but status, prestige, importance and prominence are other terms used to describe key actors. These terms, while being similar, often have a variety of definitions. Wasserman and Faust define prestige as being a measure within a directional network that evaluates an actor's influence over the network based on who they have influence over (by evaluating the indegrees of the actor) (Wasserman & Faust, pp. 174-175). The simplest measure of prestige is the total indegrees of each actor, or degree prestige,

$P_D(n_i)=d_I(n_i)$. When standardized to equal a number between zero and one,

$P_D'(n_i)=d_I(n_i)/(g-1)$ (Wasserman & Faust, pp. 202-203). In a signed network with

grouped ordinal data (-1, 0, 1), a common measure for centrality is a popularity

measurement associated with the number of likes and dislikes. As discussed in the

degree centrality section, a node is observed and the number of negative arcs is

subtracted from the number of positive arcs providing a signed centrality value. If a

network is directional, then negative indegree arcs are subtracted from positive

indegree arcs to determine this measure of prestige.

2.10 Chapter Summary

This chapter provides a history and background of AQIM and the conflict in Mali

and outlines significant social network analysis tools as applied to signed networks and

structural balance theory. This chapter is the foundation on which the methodology in

Chapter Three is developed and provides sufficient detail of the current situation in Mali

to apply the methodology to the case studies in Chapters Four and Five. After a brief

introduction to basic graph theory and social network analysis terminology, structural

balance theory is described. Then, methods for identifying subgroups within a signed

network are outlined. If a network is balanced, it can be divided perfectly into two

groups with no inconsistencies. A network is weakly balanced (*k*-balanced) when it can

be perfectly divided into *k* subgroups without any inconsistencies. Weakly balanced

networks have no cycles that have exactly one negative edge. Nodes that are positively

connected to each other are in the same subgroup in a *k*-balanced network. Two

methods for measuring imbalance in signed networks help to quantify how balanced an unbalanced network is. The existing literature for clustering signed social networks is covered and one particular method, Doreian and Mrvar's relocation method, is described in detail. Centrality measures applicable to signed data are defined as well.

3 Partitioning and Assessing Signed Social Networks

3.1 Introduction

Having highlighted in Chapter Two the major contributions to signed social networks within the literature, this chapter provides a methodology to partition and assess the signed networks. Data requirements and limitations are initially discussed. Measuring balance, the partitioning of signed networks, and evaluating the partitions are the key topics within the methodology. Two different partitioning concepts, generalized blockmodeling and relaxed blockmodeling, are discussed.

3.2 Data Requirements and Limitations

Data to populate the model is as important as the model itself. Unfortunately, when modeling dark networks, there is an inherent risk in not having complete data due to the secret nature of the organizations. Additionally, social network models are just that, models, meaning that they are abstractions of the real thing. Even when all relevant information is known about a network, decisions of what to include in the model and what to leave out are often necessary. This creates a level of uncertainty as to how well the model represents the real life situation. Any decisions based on the model must be made while considering both the assumptions of the model and other information known but not represented in the model.

Data can be collected in a number of different ways. It can be gathered in traditional ways including questionnaires, interviews, observations, historical records,

and experiments. In addition, it may be collected via national technical means and traditional intelligence practices. Once data is collected, it is necessary to review the data to ensure that it meets the requirements for the model. In this case, we require data that reflects each relationship as positive, negative or neutral {1, -1, or 0}. If data exists in another form, it must be converted into this form. If the data calculates a relationship as a probability of having a positive (negative) relationship, a cut off value, β is required. Any probability below β would be a null relationship, reflected as a zero. Any probability at or above β is a one (or negative one). This method converts probability of having a positive or negative relationship into the appropriate format. Sometimes multiple binary datasets can be combined to make a grouped ordinal dataset. In this case, one binary dataset represents positive relations where another dataset represents negative relations. This data can be converted to the appropriate format by multiplying the negative relations adjacency matrix by negative one and adding the two matrices.

3.3   Partitioning Signed Networks with Generalized Blockmodeling

3.3.1   Partitioning a Balanced Network.

Once data is collected and properly formatted, it can then be analyzed to determine whether the network is balanced or not. One way to identify a balanced network is to determine that all of its cycles are positive (Cartwright & Harary, 1956). The sign of a cycle is calculated by taking the product of the edges. The easiest negative cycle to identify in a network graph is often one with only one negative line. Even if only

one negative cycle exists in a large network of all other positive cycles, the network is unbalanced. Guaranteeing a network is balanced is difficult in large networks because all cycles need to be identified and found positive in order to be sure it is balanced. Therefore, it is often easier in large networks to use a heuristic to check if a network is balanced.

The Doreian/Mrvar heuristic uses an optimization method to determine the best clustering option for network data. This method, called the relocation method, uses a criterion function, P(C), to determine how well a blockmodel fits the data. $P(C) = N+P$ where N is the number of negative ties within subsets and P is the number of positive ties between subsets. This criterion function was developed based on social balance theory and any value that is either a positive tie between subsets or a negative tie within a subset is defined as an inconsistency. The criterion function is then minimized to determine the local minimal optimum. Finding the partition with the least number of inconsistencies identifies the most balanced network possible with the given relationships. Since the relocation method identifies a local optimal value, the minimum criterion function is repeatedly calculated to verify the minimum local optimal value is found. This calculation is done for all values of k from one to n, the number of actors in the network. The heuristic is presented in the following steps (Doreian, Batagelj, & Ferligoj, 2005, p. 150):

1. Select a value of k.

2. Randomly determine an initial clustering, C, with k clusters.

3. Repeat: If, in the neighborhood of the current clustering C, there exists a clustering C' such that P(C') < P(C), then move to C'. The neighborhood of a clustering C is determined by two transformations:

(a) moving a vertex from one cluster to another cluster and

(b) interchanging two nodes between different clusters. This process is repeated many times (in the order of many thousands) to minimize the risk of reaching only a local minimum rather than a global minimum.

4. Repeat the whole procedure for different values of k.

If all of the cycles have been found to be positive or the minimum criterion function of the relocation method is equal to zero for some value k, then the network is balanced and can be partitioned without any inconsistencies into k subsets. This partition completely supports structural balance theory and there is little to no tension within the network. This type of network is the ideal situation when modeling people or groups of people. However, this type of situation rarely exists in large, real-life networks. If the minimum criterion function is greater than zero, the network is imbalanced. The next section describes how to partition imbalanced networks.

The relocation method can be quickly calculated using PAJEK software (Batagelj & Mrvar, 1996). For this research PAJEK version 3.08 was used for all blockmodeling and relocation method calculations. The number of repetitions used per k was 1,000 and $\alpha = 0.5$. Figure 14 provides a flow chart of the entire methodology discussed in this chapter.
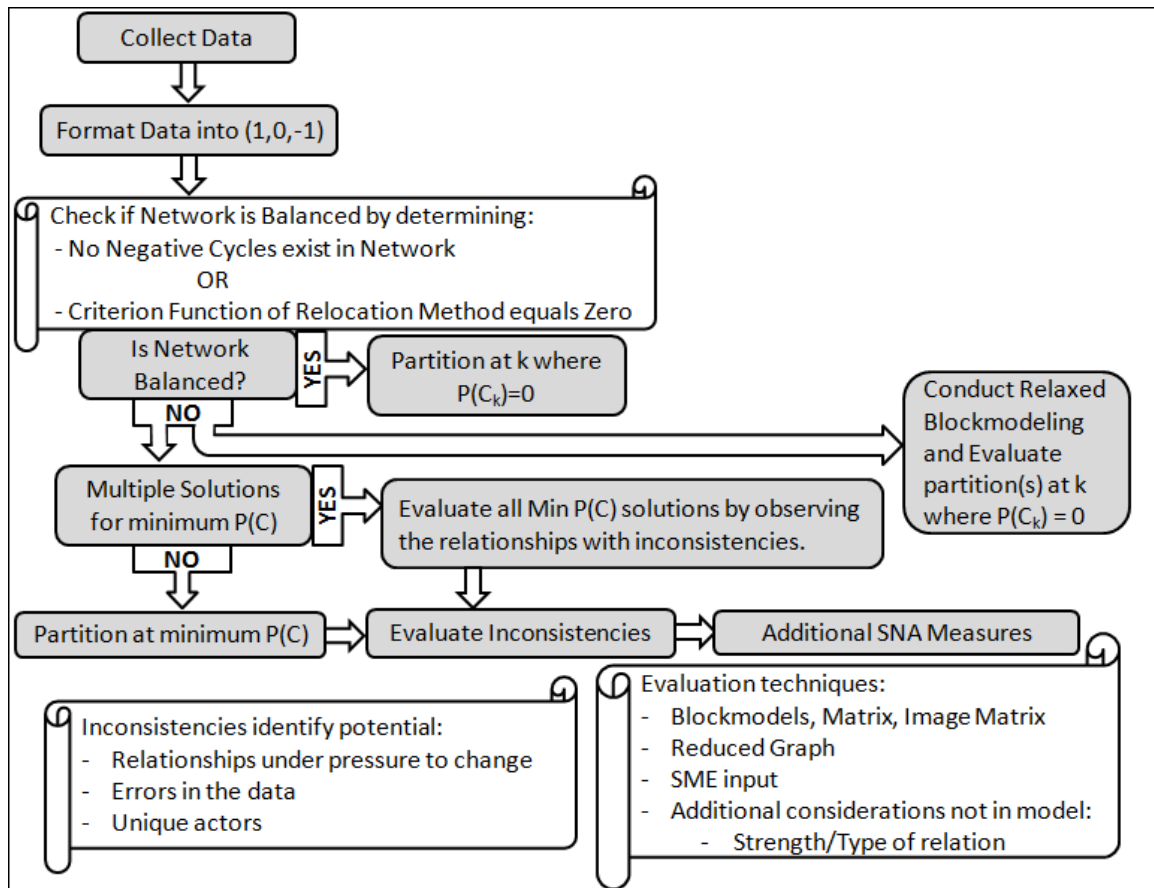
Figure 14: Methodology Flow Chart

3.3.2 Partitioning Imbalanced Networks.

The Doreian/Mrvar heuristic used in the relocation method is an effective way to determine the optimal number of partitions for a given network. As previously discussed, this method quickly solves the criterion function to find the minimum number of inconsistencies for all partitions one to *n*. The number of partitions associated with the smallest criterion function identifies the best way to partition the network, so that the fewest inconsistencies exist with enough trials. When the network is partitioned in this way, it is the most balanced it can be without changing any relations in the network. As an example, if a network consisting of four nodes with the

relationships shown in Figure 15 is partitioned, none of the partitions result in zero

inconsistencies. Alternatively, this network is determined to be unbalanced because the

cycle A-B-D-A has exactly one negative relationship.
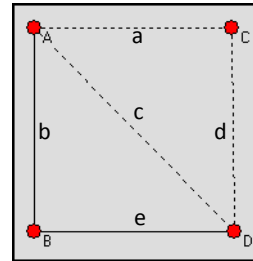
Figure 15: Notional network matrix and graph with four actors. Dashed lines represent negative relations and solid lines represent positive relations. Graph by author using Pajek (Batagelj & Mrvar, 1996)

Unfortunately, occasionally a network will have the same minimum number of

inconsistencies for more than one value of k. Additionally there can be multiple ways a

network can be divided into k partitions with the same minimum number of

inconsistencies. In the unbalanced network in Figure 15, two values of k (k = 2 and k =3)

result in the minimum of one inconsistency (see Table 4). Since the minimum number

of inconsistencies identifies the best partitioning of the network, this network is best

partitioned into either two or three subsets. This particular network can be partitioned

into two different subsets of three making three total options that have the minimum

number (one, in this case) of inconsistencies.

Table 4: Inconsistencies of graph in Figure 15

# of subsets	1	2	3	4
Minimum # of Inconsistencies (Criterion Function)	3	1	1	2
# of possible different subsets with Minimum # of Inconsistencies	1	1	2	1

If relationship c is removed, then the network would be balanced with two

subsets {A,B,D} and {C}. If the relationship b is removed, the network would be 3-

balanced with {A}, {C}, and {B,D} as the subsets. If the relationship e is removed, the

network is again 3-balanced, this time with {A,B}, {C}, and {D} as the subsets. Therefore

three different ways to partition this network have been found to make it as close to

balanced as possible. Using Equation 1, restated here as Equation 8, the total possible

number of partitions of a four actor network can be determined to be fifteen.

$$S(n,k) = \frac{1}{k!}\sum_{i=0}^{k}(-1)^{k-i}\binom{k}{i}i^{n}$$

The relocation method finds the partitions that best fit a balanced network out of the

total number of partitions. In this simple case it narrows the number of partitions to

investigate further to three from fifteen, allowing one to look deeper at the

relationships in only these three groupings.   This is important because as networks

grow, the number of partitions increases exponentially. For example in Chapter Four,

we will observe a seven actor network that can be partitioned 877 different ways,

adding an eighth actor pushes the number up to 4,140, and Chapter Five's ten actor

network can be partitioned 115,929 different ways. It is therefore necessary to have a

method that quickly identifies a limited number of partitions that are close to balanced

that can be analyzed more closely.

3.4   Partitioning Signed Networks with Relaxed Blockmodeling

While the generalized blockmodeling approach provides some depth and understanding to the situation, relaxed blockmodeling approaches the problem differently, providing different insights. As the name suggests, relaxed blockmodeling relaxes the requirements of positive blocks being on the diagonal and negative blocks being off the diagonal. This relaxation allows for exceptions to the social balance theory in order to identify unique relationships like mediators whose relations would otherwise be classified as inconsistencies. The relaxed approach is based on the theory that there are other forces outside of structural balance theory that contribute to the clustering of actors within a network. This approach still allows for structural balance theory (by letting positive blocks still appear on the diagonal and negative blocks off the diagonal), but also allows other options. The relaxed blockmodeling approach should be conducted if there are multiple solutions for the generalized blockmodeling approach or if the minimum inconsistency found in the generalized blockmodeling approach is high. With the relaxed constraints, the relaxed blockmodeling approach may find a better partition or more logical fit to the network in these situations.

In relaxed blockmodeling the presence of positive and negative blocks and the criterion function remains the same, except now any signed block can appear anywhere within the blockmodel. The criterion function for a relaxed blockmodel is most easily understood as: $P(C) = N+P$ where N is the number of negative ties in positive blocks and P is the number of positive ties in negative blocks. The same relocation method as used

in generalized blockmodeling is used in relaxed blockmodeling to determine the number of inconsistencies. However, different from generalized blockmodeling, in relaxed blockmodeling the values of $P(C_k)$ decline monotonically as k increases (Doreian & Mrvar, 2009). Therefore as k gets higher, $P(C)$ approaches zero. When $P(C_k)$ equals zero the network can be partitioned at k with zero inconsistencies.

When a relaxed blockmodel has zero inconsistencies and there are no negative blocks on the diagonal, then the graph can be reduced to the identified subsets without losing any information. However, when there is a negative block on the diagonal where the actors in the diagonal negative block have the same relations to all other actors, but dislike each other, reducing would result in the actors in that block being identified as liking each other. Therefore, if those actors are clustered into the same group to reduce the graph, the internal relationship between actors in that node needs to be kept track of as negative.

A mediator, a positive link that can negotiate between two dissenting actors, can be identified in several different ways. In a relaxed blockmodel with zero inconsistencies, a negative block on the diagonal where the actors dislike each other, and a positive block in the same row or column, the mediator(s) is the actor(s) in the positive block. Additionally, when a relaxed generalized blockmodel has zero inconsistencies and an actor (or in a reduced graph, group of actors) has more than one positive non-diagonal block in their column or row, the actor is a mediator between the actors in the positive blocks. The proof is trivial because there are zero inconsistencies,

making any actor with more than two non-diagonal positive blocks someone who likes the actors within those blocks while those actors cannot like each other or they would be in the same block.

3.5   Evaluating the Partitioned Network

3.5.1   Social Network Measures.

The popularity of an actor in a signed network can be a useful measurement because a more popular actor is assumed to have more influence within the network.   This thesis uses three different measures to calculate the popularity of individual actors within the network. The three metrics for evaluating signed networks are likes minus dislikes, ratio of likes, and eigenvector centrality. Likes minus dislikes is a quick snapshot of the network by subtracting the dislikes from the likes each actor has in the network. This will return an integer value. A positive value means the actor has more friends than enemies in the network, where a negative value means the opposite. The actors can then be ordered and compared to determine who might have the most influence within the network.

The second measure, the ratio of positive (or negative) degree over the total degree (both positive and negative) will denote the proportion of friends (enemies) the actor has within the network. The ratio measure provides a better indication of how popular an actor is based on the relations that he or she has. For example, if actor A has three positive out of four total relations and actor B has one positive out of two

relations, both will have a likes minus dislikes value of one, but actor A will have a 0.75

ratio and actor B will have a 0.5 ratio. This shows that the ratio measure is a potentially

preferable approach to use in sparse networks than the positive minus negative

measure.

The third measure, eigenvector centrality is a measure of how central an actor is

to the network based both on how many connections the actor has and the influence of

connected actors. This measurement attempts to measure both the number of

connections as well as how important the connections are.   Eigenvector centrality

provides the centrality of the actor, x, by using the largest eigenvalue, λ, of a symmetric

adjacency matrix, A. This relationship is shown in Equation 9.

$$x = \frac{1}{\lambda} A x$$
<div align="right">Equation 9</div>

Eigenvector centrality when applied to signed networks can increase the status of a

node by having a positive connection to a high status node or a negative connection to a

low status node. It can also decrease the status of a node by having a negative

connection to a high status node or a positive connection to a low status node.

Unfortunately, eigenvector centrality can only be used with non-directional data

because a symmetric adjacency matrix is needed to ensure a positive eigenvalue

(Bonacich & Lloyd, 2004). In this thesis, eigenvector centrality was calculated using

UCINET 6 for Windows (Borgatti, Everett, & Freeman, 2002).

3.5.2 Evaluating Inconsistencies.

Once the best fit partitioning of the network has been identified, they can be

further examined. One way to do this is by looking at the blockmodels of each of the

partitions and identifying the inconsistencies in each blockmodel. Recall, from section

2.6.3.3, that a positive value in a block off the diagonal and a negative value inside a

diagonal block is an inconsistency in generalized blockmodeling. To determine which

relationships are under the most tension to change, sum the total number of

inconsistencies belonging to each relationship identified from all of the subsets with the

minimum number of inconsistencies. The three blockmodels for the best partitions of

the notional network in section 3.3.2 are shown in Figure 16. Within each blockmodel is

an inconsistency that is highlighted. For this simple example, inconsistencies are found

once in three different relationships. However, if one relationship was found more

often, this relationship would be identified as having more tension and therefore would

be more likely to change.

	A	B	D	C
A		1	-1	-1
B			1	
D				-1
C				

3 subsets, 1 Inconsistency

	A	B	D	C
A		1	-1	-1
B			1	
D				-1
C				

3 subsets, 1 Inconsistency

	A	B	D	C
A		1	-1	-1
B			1	
D				-1
C				

2 subsets, 1 Inconsistency

Figure 16: Blockmodels for notional four actor symmetric network

Suppose that the individuals in our example are Adam, Barb, Chris and Donna (A,

B, C, and D respectively). Adam and Barb are married. Donna and Barb are friends, but

Barb's husband, Adam does not get along with Donna. Chris is an acquaintance of Adam and Donna, but neither of them like him much. Barb and Chris do not know each other. As discussed previously there are three different ways to partition this network where each partition has one inconsistency. The far left blockmodel identifies the Adam/Barb relationship as being inconsistent. Given what is known about the network, the Adam/Barb relationship is probably the strongest (since they are married) and therefore is unlikely to change.

The other two blockmodels identify Donna's relationships with Barb and Adam. It is likely that one of these two relationships will change to make the network balanced. One option is that Barb will stop associating with Donna because Adam does not like her. The other option is that Adam will tolerate (and maybe eventually begin liking) Donna to preserve Barb's relationship with her. In all situations Chris is in a group by himself.

In evaluating the best partition of a network, additional analysis is required (such as how much one likes/dislikes another) to identify which relationship is most vulnerable to change. For example, the Adam/Barb relationship may be the most vulnerable to change if the analyst knows that Adam and Barb have been having marital problems. On the other hand, if Donna is identified as Barb's mother, the source of tension within the network may suddenly make sense. In this case, the Adam/Donna relationship is one that both parties will likely try to improve to move the network into balance, resulting in less strife at home. The model does not take these types of

relationships into account but rather requires SME's to apply the intangible details of relationships to identify the appropriate partition when multiple partitions exist. The model reduces the number of partitions into a manageable amount to evaluate individually and aids in highlighting relationships that may require more detailed analysis.

3.6   Chapter Summary

This chapter provides the basic understanding for how a signed network can be partitioned and evaluated. A small example was provided demonstrating how to measure imbalance within a network by identifying inconsistencies via generalized blockmodeling. Relaxed blockmodeling was presented as an alternative to generalized blockmodeling when there are many minimum P(C) solutions or when there is a high minimum inconsistency identified in the generalized blockmodeling approach. Once the best solution or solutions are found by minimizing the criterion function, they should be evaluated by subject matter experts to identify potential causes for the inconsistencies. Chapters Four and Five provide case studies that further apply the methodology described in this chapter.

4   Mali Militant Groups Case Study Pre-French Intervention

4.1   Introduction

This chapter seeks to apply the outlined methodology to seven militant groups in Mali to identify the alliances of these groups and to determine which relationships are susceptible to change or which relationships may be mischaracterized by current understanding. The values assessed in the model presented in this chapter are based on relationships prior to the 11 January 2013 French involvement in the Malian conflict.

There are 877 different ways to partition a network with seven actors (Equation 1, page 2-41). However, most of these ways, while mathematically possible, do not make sense based on the known relationships between the actors. Due to the complex web of relationships, it is often difficult to find a partition that does not misrepresent at least one relationship. In an unbalanced network there is always a relationship or relationships that contradicts what two actors would be expected to maintain when looking at the relationships in the rest of the network. The methodology outlined in Chapter Three identifies the best possible partitions within the network to minimize those inconsistencies. The partitions that are found can provide indications to how a network's web of relationships may evolve and can provide intelligence analysts additional insight into the groups or alliances that form. Additionally it can indentify actors that fill the role as mediators between groups or potentially find misclassified relationships or erroneous data within the network.

4.2 Background

Until recently Mali was considered a democratic model in Africa (Aziz, 2013). However, in March 2012 a military coup ousted Malian President Amadou Toumani Touré. In the aftermath of the coup, basic governance and security broke down in Northern Mali allowing for a disgruntled Tuareg movement to rebel against the state. This movement, initiated by the National Movement for the Liberation of Azawad (MNLA) and later co-opted by Islamic extremists, is the most recent in a series of Tuareg rebellions in Mali. Within the conflict in Northern Mali, there are a number of key groups that are influential in shaping the events. The relationships between these actors are explored in order to identify subsets of potential alliances and potential vulnerabilities.

4.3 Key Actors

The study in this chapter explores the relationships between seven actors: AQIM, MUJAO, AAD, MNLA, Arab Militias, the Patriotic Forces of Resistance (PFR) and Mali government affiliated forces in 2012, prior to French involvement on 11 January 2013. Each of these actors and their relations to each other are discussed in this section. Section 2.2 has a detailed overview on AQIM and should be referenced for historical, geographic and cultural significance of AQIM and the region as a whole. Section 2.2.4 provides additional background on some of the key actors affiliated with AQIM (MNLA, AAD, MUJAO), and whose relationships are analyzed in this chapter. Table 5 provides an overview of the key actors described in section 4.3.

Table 5: Key Actors in Northern Mali (Pre-French intervention)

Number	Group	Ideology	Goal	Ethnicity	Area of Operation	Like	Dislike
1	MNLA	Secular	A secular, independent government in Azawad	Primarily Tuareg	Kidal	3	2,4,5,6
2	AQIM	Extreme Islamic	Establish an Islamic Caliphate throughout Muslim world	Algerian leadership, African participants	Timbuktu/ Dispersed across Northern Mali	3,4	1,6,7
3	AAD	Extreme Islamic	Establish an Islamic State of Mali with Shari'a Law enforced	Primarily Tuareg leaders, other ethnic participants	Kidal/Timbuktu	1,2,4	6,7
4	MUJAO	Extreme Islamic	Establish an Islamic Caliphate throughout Muslim world	Mauritanian leader, African participants	Gao/Menaka	2,3	1,6,7
5	Arab Militias	Islamic	Defend and protect there own interests	Arab	Lere/Timbuktu	6	1,7
6	Malian Govt	Secular	Regain control of their territory and defeat the rebel movement	Bambara, Peuhl, Senufo, Songhai, Dogon, Malinke and others	Mopti, Sevare	5,7	1,2,3,4
7	FPR	Secular	Regain control of lost Mali territory and defeat the rebel movement/Revenge	Songhai, Peuhl, Bozo, Bella and others	Originally Gao and Douentza, moved south when Islamists took over North	6	1,2,3,4,5

4.3.1 National Movement for the Liberation of Azawad (MNLA).

The National Movement for the Liberation of Azawad (MNLA) is a largely secular group whose goal is to liberate and establish a separate government in the area they refer to as Azawad, the desert region in Northern Mali. The movement is largely made up of ethnic Tuareg fighters. There were previously at least three Tuareg rebellions, fighting Mali for independence. The most recent rebellion, fueled by returning fighters and weapons from post-Gaddafi Libya, began in January 2012. Members of the Malian military, unhappy with how the government was handling the rebellion, coordinated a coup on 22 March. Following the coup, the government forces put up little resistance, allowing the MNLA, with assistance from extremist Islamic fighters, to gain control over large portions of Northern Mali. In April 2012 the MNLA issued a declaration of

independence for Azawad. Shortly after independence, Ansar Al-Din and MUJAO began enforcing Shari'a law in areas they controlled. The MNLA, in favor of a more tolerant form of Islamic government, objected to imposing Shari'a on the population. This led to disagreements between the MNLA and the Islamic extremist organizations. Battles began to take place throughout Northern Mali with MNLA losing control of much of the territory to Ansar Al-Din and MUJAO (BBC News, 2012). Once consisting of thousands of fighters, MNLA's power seemingly diminished with power and influence shifting to Ansar Al-Din. As a result, the MNLA reengaged with the Malian government for support against extremists (Oumar, 2012) and attempted to negotiate with moderate Tuareg members in Ansar Al-Din to establish a more united Tuareg organization (El Hadi, 2012).

The MNLA has negative relations with AQIM and MUJAO and repeatedly claims to oppose all terrorists (McGregor, 2012). The relationship between MNLA and Ansar Al-Din is complicated. Both groups are led by and have active memberships from the influential Ifoghas Tuareg tribe. This study characterizes the relationship as positive due to strong bonds that exist between Tuareg members within both organizations. Since April, the MNLA and Ansar Al-Din have had conflicting relations due to their differences in ideology, mainly the implementation of Shari'a law (Jacinto, 2012). The MNLA and Ansar Al-Din have had an off and on relationship since the establishment of both organizations. They briefly merged in May and both signed an agreement in December 2012 for a ceasefire with the government (Reuters, 2013). However, neither of these agreements lasted long (the December deal was rescinded by AAD on 3 January 2013).

FPR, Arab militias, and government militias generally have negative relations with the MNLA based mostly on ethnic differences that have historically caused conflict and disagreements.

4.3.2 Al-Qa'ida in the Islamic Maghreb (AQIM).

Al-Qa'ida in the Islamic Maghreb (AQIM) is an Al-Qa'ida affiliated terrorist organization formerly known as the Algerian Salafist Group for Call and Combat (GSPC). On 11 September 2006, Al-Qa'ida's second in command, Ayman al-Zawahiri, announced the merger of GSPC with Al-Qa'ida. In January 2007, the GSPC announced their new name: Al-Qa'ida in the Islamic Maghreb. The name change reflected the evolution of the organization from a local to a global jihad with the goal of establishing an Islamic Caliphate and conducting jihad on anyone opposed to their mission. AQIM then began to target foreign countries and operate outside the borders of Algeria, especially in Mali and Mauritania (Harmon, 2010, p. 16). In recent years, due in part to Algerian success in targeting AQIM leadership based in Algeria, AQIM has found the openness of the Sahara an ideal place to operate. AQIM's history of smuggling operations within this region has allowed them to expand relationships with the local population to facilitate their operations. When the conflict in Northern Mali started, AQIM was positioned to capitalize on those relationships and use the weapons, money and influence they possess to enable Islamic extremists to control most of Northern Mali. While it is unclear the level of interaction between the different extremist organizations, AQIM is active and involved in Northern Mali. It is closely aligned in ideology to MUJAO and

Ansar-Al Din while the MNLA, FPR and Malian government militias are opposed to AQIM.

4.3.3 Ansar Al-Din (AAD).

Ansar Al-Din ("Supporters of Religion" or "Defenders of Faith") is a new organization inside Mali led by Iyad Ag Ghaly, one of the leaders in the Tuareg rebellion in the 1990's. There are strong indications that Ansar Al-Din is associated with AQIM, based on their common goal of establishing an Islamic state and the connections of Ag Ghaly with some of AQIM's leaders (Metcalf, 2012). Ansar Al-Din fought alongside the MNLA in Northern Mali, but after taking control of Azawad, the differences between MNLA and Ansar Al-Din became too great. In the Battle of Gao, on 27 June 2012, Ansar Al-Din and MUJAO defeated the MNLA and took control of many of the cities in Northern Mali (BBC News, 2012). Ansar Al-Din and MNLA are both led by individuals from the Ifoghas Tuareg tribe, making them close despite the conflict. Ansar Al-Din's goals differ from the MNLA in that they want Mali to remain united and for Shari'a law to govern the whole country (BBC News, 2012). Ansar Al-Din appears to represent the people of Azawad better than any of the other organizations analyzed. It's make up is different throughout Northern Mali with Arab, Songhai and other ethnic groups represented within the organization, especially in areas where those ethnicities make up the majority of the population, such as Timbuktu (Tanchum, 2012). Being more diverse can be a strength or a weakness, as it provides them with a wider base, but potentially more conflicting voices.

Based on the reasons discussed in the previous paragraph, Ansar Al-Din has positive relations with AQIM, MUJAO, and MNLA. FPR groups and Ansar Al-Din have negative relations based on ideology and historical ethnic conflicts. Some may argue that the relation between Ansar Al-Din and the government of Mali should be classified as negative based on Ansar Al-Din's current relationships with AQIM and MUJAO and their statements and actions of implementing Shari'a law throughout Mali. However, the previous Mali government has a long history of dealing with Ag Ghaly who has a history of making deals with all parties, therefore this study characterizes this relation as null (neither positive nor negative). Additionally, Ansar Al-Din has already shown a willingness to come to the table for negotiations, something that AQIM and MUJAO are unlikely to do (Reuters, 2013).

4.3.4 The Movement for Oneness and Jihad in West Africa (MUJAO).

The Movement for Oneness and Jihad in West Africa (French: Mouvement pour le Tawhîd et du Jihad en Afrique de l'Ouest) (MUJAO) is an AQIM off-shoot in West Africa. The organization is led by Mauritanian national Hamada Ould Mohamed Kheirou (a.k.a. Abou QumQum) and is seen by many as a way to expand the mission of AQIM. Other analysts see the creation of MUJAO as evidence of AQIM splintering due to the native Algerian leadership's unwillingness to allow non-Algerians to rise through the ranks (Cristiani, 2012). MUJAO appears to be made up of mostly Moors and Arab people from West Africa. MUJAO is closely aligned with AQIM and parts of Ansar-Al Din. It is in conflict with MNLA, FPR and the Malian government militias. This study classifies

the relationship between MUJAO and Arab militias as null since they tend to operate in the same areas and tolerate each other, but they have different backgrounds and ideologies.

4.3.5   Arab Militias.

Historically Arab militias have operated in the Timbuktu and Gao regions with the government's support[4]. Arab militias have previously been used by the government to fight against Tuareg separatists and help protect the northern Arab population during the previous Tuareg rebellions. Using Arab and Tuareg militias to assist in fighting the Tuareg rebellions exacerbated long term ethnic problems within and between different northern communities. Although at times legitimized and even commanded by Malian army officers, these militias are widely believed to participate in the illegal smuggling networks that operate throughout Northern Mali. Additionally, these militias both compete and cooperate with Tuareg and Islamic groups that participate in similar smuggling activities. This illicit network of smuggling drugs, cigarettes and other goods has encouraged the establishment of private militias throughout Northern Mali to protect both legitimate and non-legitimate business interests (van Vliet, 2012). The Arab Militias have had a generally good relationship with the Malian government. It is difficult to say what policy the new government, when in place, will take towards these militias. The Arab militias have historically negative ties to the FPR affiliated groups and

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[4] "The principal Arab (Moors) groups residing in northern Mali are the Kunta and Telemsi (concentrated in the Gao region) and the Berabiche (of which a majority reside in Timbuktu, but who are scattered around the entire region). They formed the backbone of the militant Arab Islamic Front of Azawad (FIAA)" (van Vliet, 2012).

to the MNLA and most Tuareg groups. Their relation with the Islamic militants is null because in at least some cases, militias continue to operate throughout their normal territory and have been able to coexist with the extremists. In some cases, Arab militias may be participating with certain Islamic extremist groups to achieve like interests.

4.3.6   Mali Government Affiliated Forces.

Mali's military has historically been "underpaid, poorly equipped, and in need of rationalization (Library of Congress, 2005)". Additionally, efforts to incorporate former Tuareg rebels into the Army created infighting and a struggle for power between the competing military commanders. Following the coup, the Army that was stationed in Northern Mali dissolved. Three senior Malian officers still have troops and the desire to fight to regain Northern Mali. Colonel al-Hajj Gamou is a Tuareg that escaped into Niger when the Malian army disintegrated in the region. He reportedly has 600 pro-government Tuareg fighters to assist in retaking the north (McGregor, 2012). Colonel Ould Meydou, an Arab, took refuge in Mauritania and can return to fight with the approximately 1,000 man Arab force that he commands (McGregor, 2012). Colonel Didier Dakuo commands approximately 2,000 regular army soldiers with some vehicles and equipment at the military base in Sévaré, just south of the territory the Islamists control (McGregor, 2012). These forces remains poorly equipped and suffer from mistrust, poor discipline and a lack of leadership. Additional Malian military was disbanded in the aftermath of the coup. Mali has a small Air Force and Navy, but their equipment is old and poorly maintained (Library of Congress, 2005). The Mali

government forces (at least some pro-government militias) have existing positive

relations with the Arab militias. The FPR are decidedly pro-government and will support

government forces in any action. Government forces are opposed to the Islamists

occupying Northern Mali including MNLA, Ansar Al-Din, AQIM and MUJAO.

4.3.7 Patriotic Forces of Resistance (FPR).

Several self-defense militias have operated in Mali since the 1990's. Although

the Malian government has previously made efforts to crack down on them or

incorporate them into the Army, the recent conflict has produced a large number of

pro-government militias. Recently six of them have joined together to make up the

Patriotic Forces of Resistance (FPR) (Look, 2012). The two largest groups making up the

FPR are the Ganda Koy (Lords of the Land) and Ganda Iso (Son of the Land) with

estimated forces of 2,000 and 1,300 fighters respectively (Jamestown Foundation,

2012). These militias have received training and logistical support from the Malian

Army, but have not been given arms or a formal role in the attempt to retake the North.

In addition to the Ganda Koy and Ganda Iso, the other groups in the coalition are: the

Liberation Forces of the Northern Regions (FLN), the Alliance of Communities from the

Timbuktu Region (ACRT), the Armed Force against the Occupation (FACO) and the

Thought and Action Circle (CRA) (Jamestown Foundation, 2012). These predominately

Songhai and Peuhl/Fulani groups blame the MNLA and the Islamic groups for raping,

killing and stealing from them in addition to forcing Shari'a law upon them. Human

Rights Watch reports that "these militias, as well as youth groups made up of members

of northern ethnic groups – the Songhai, Peuhl, Bozo, and Bella – had apparent plans to "settle scores" with their perceived northern opponents (Human Rights Watch, December 2012)." There have been reports of "kill lists" being created as well. While there is a rich history of ethnic coexistence within Mali, there seems to be a genuine concern that the recent alleged war crimes on all sides, if left unaddressed, could continue and grow worse if these groups are used by the Malian government to attempt to retake control over Northern Mali. For all of these reasons, the FPR have positive relations with the Malian government affiliated forces and negative relations with the MNLA and each of the extreme Islamist groups. The FPR also generally have negative relations with the Arab militias due to ethnic differences. The Malian government historically pits different militias against each other in order to maintain control, thereby worsening ethnic cleavages (van Vliet, 2012).

4.4 Assessing Relationships between Actors

The previously identified groups and their relationships as discussed in Section 4.3 outline the background and provide the basis for the analysis. The relations between these groups are shown in the matrix in

Table 6. It should be noted that the relationships in this illustrative example are the assessment of the author, based on open source literature. Actual relationship values should be provided by regional, cultural and subject matter experts.

Table 6: Mali actor's relationship matrix (Pre-French Intervention)

	MNLA	AQIM	AAD	MUJAO	Arab Militias	Malian Govt	FPR
MNLA		-1	1	-1	-1	-1	-1
AQIM	-1		1	1		-1	-1
AAD	1	1		1		-1	-1
MUJAO	-1	1	1			-1	-1
Arab Militias	-1					1	-1
Malian Govt	-1	-1	-1	-1	1		1
FPR	-1	-1	-1	-1	-1	1	

This set of relationships creates a symmetric matrix because all relationships are reciprocated (if actor *i* likes actor *j*, then actor *j* also likes actor *i*). The matrix in
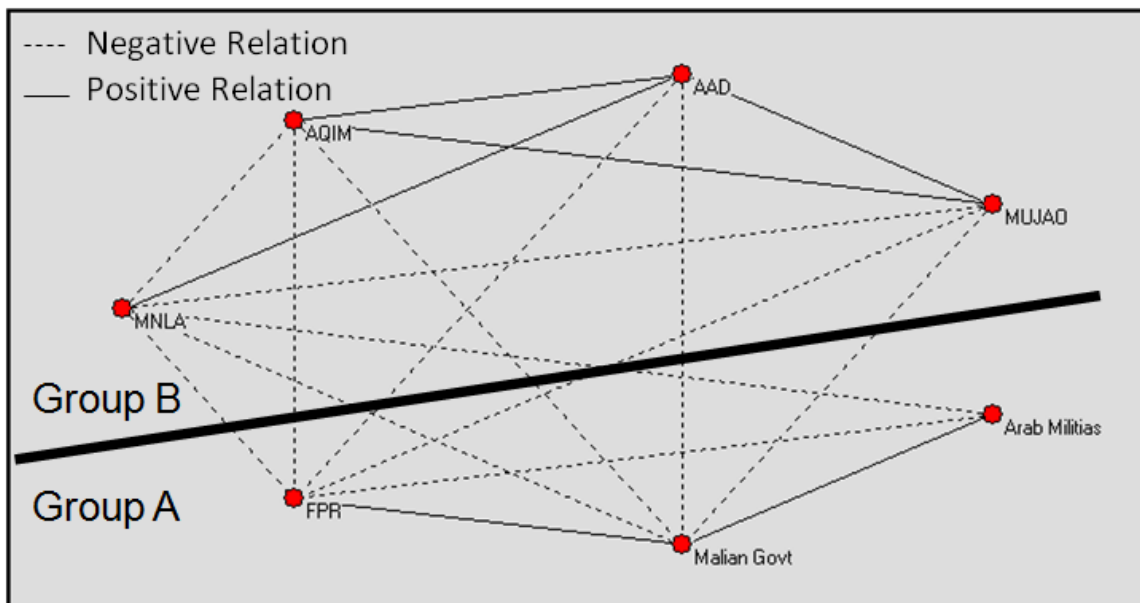
Table 6 is displayed in graph form in Figure 17.

Figure 17: Network of relationships from

Table 6 shown in graph form.　　　　　　**Graph by author using Pajek (Batagelj & Mrvar, 1996)**

4.5   Partitioning Actors into subsets

4.5.1   Generalized Blockmodeling.

When looking at the graph in Figure 17, partitioning the network into two

subsets may seem obvious due to the negative lines drawn between Arab militias,

Malian government, and FPR in one group (referred to as group A) and everyone else in

the other (group B). However, when looking at each of these subsets, they are not

balanced because there are three negative relationships within subsets (three

inconsistencies; MNLA-AQIM, MNLA-MUJAO and FPR-Arab Militias). Since initial

partitioning is not balanced, additional partitioning options need to be explored.

Therefore the relocation method can be used to calculate the minimum inconsistency

for all k using Pajek (Batagelj & Mrvar, 1996) with $\alpha = 0.5$. As Table 7 shows, when the

network is partitioned into three or four subsets, the least number of inconsistencies

exist and the network best fits a partition of three or four subsets. In each case, two

inconsistencies exist demonstrating that if two relationships are negated, reversed or

deleted, then the network will become balanced and there will be significantly less

tension. There are two different possible subsets that have two inconsistencies when

partitioning into both three and four subsets. Therefore there are four different

solutions that solve the minimum inconsistencies criterion function.

Table 7: Minimum inconsistencies for all possible partitions

# of subsets	1	2	3	4	5	6	7
Minimum # of Inconsistencies (Criterion Function)	10	3	2	2	3	5	6
# of possible different subsets with Minimum # of Inconsistencies	1	1	2	2	1	6	1

To determine which of the subgroups with the minimum number of

inconsistencies makes the most sense, further analysis is required. Initially the four

blockmodels that provide the minimum answer to our criterion function should be

observed. These blockmodels are shown in Figure 18.

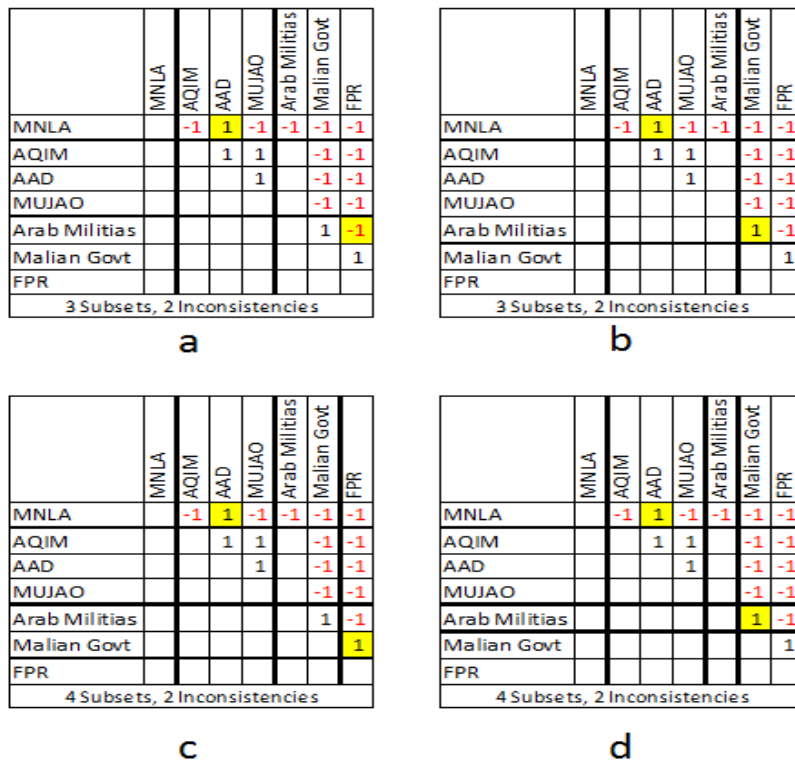**Figure 18: Blockmodels of the four different partitions found by minimizing the criterion function. (Matrices are symmetric. Highlighted blocks show inconsistencies.)**

In evaluating these blockmodels, the inconsistent relationships should be summed for

all of the different blockmodels. This results in MNLA/AAD relationship being identified

in every blockmodel, a total of four times, Arab militias/Mali government relationship

being identified two times, and Arab militias/FPR and Mali government/FPR each identified once.

Since the MNLA/AAD relationship is identified as an inconsistency in every minimum inconsistency blockmodel, it is clearly a relationship that should be studied further. This relationship should be reevaluated to determine if is misclassified and should be classified as negative or if it has been found because there is a great deal of tension and pressure for this relationship to change. Since the people within these two groups are culturally intertwined, given that these two groups are largely Tuareg, it seems possible that this relationship will remain positive and not change to negative. The sticking point in the relationship is that Ansar Al-Din has a much more religious stance than the MNLA and is linked with AQIM and MUJAO. However, in the event of a UN backed military mission, Ansar Al-Din may be forced to choose sides. AAD can be expected to choose the side that they perceive will enable them the most long term power and influence. This study hypothesized that AAD would denounce violence and extremism and fall into the subgroup of MNLA. This would make AAD's relationship with AQIM and MUJAO negative and keep their relationship with MNLA positive.

The relationship with the second most inconsistencies is the Arab militias/Mali government relationship. This relationship is in two of the blockmodels, Figure 18b and Figure 18c. In both of these instances the relationship should be changed from positive to negative to make it consistent. When this relationship was initially evaluated, it was rated as positive because of the Malian government's history of working with Arab

militias to fight Tuareg insurgencies. However, the Arab militias seem to be complicit with some extremists and if that continues the Malian government may wish to cut ties with the Arab militias. Therefore, this relationship is under tension to change and could be targeted with influence operations to assist in facilitating that change.

The other two relationships were identified as inconsistencies only one time. In Figure 18a, the relationship that is inconsistent with the blockmodel is between Arab Militia and FPR. Even though this is identified as a source of tension in this model, it is not likely to change due to the deep ethnic divide between the two groups. In Figure 18d the relationship that is inconsistent with the blockmodel is between the Malian government and FPR. While it can be argued that these groups have a negative or null relationship, they are firmly in the same camp with regards to Northern Mali and the insurgents there. Therefore, this relationship is not likely to turn negative unless they take up arms without government permission to avenge past wrongs. The relationship could turn null if the Malian government addresses some of the FPR's concerns on human rights abuses and limits future ethnic conflict escalation. In this case, the FPR organizations would likely cease to be influential within the network.
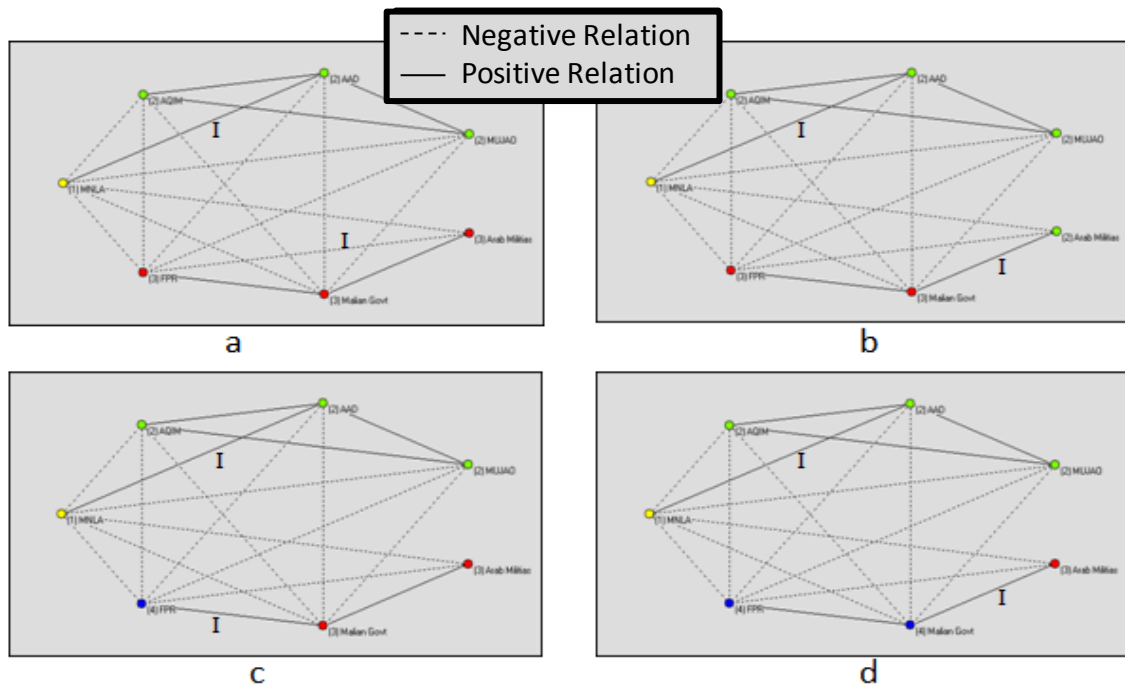
Figure 19: Network graphs of the four different partitions. Graphs by author using Pajek (Batagelj & Mrvar, 1996)

If the two relationships with the most inconsistencies were to change, it would create a balanced network. Since the Arab Militia relationships are currently sparse, the Arab Militia could be included in either the Islamist extremist or the FPR/Malian government subsets or form its own. Better intelligence indicating the Arab militias actual relations with AAD, AQIM and MUJAO would indicate which subset into which they should be placed.

	MNLA	AAD	AQIM	MUJAO	Arab Militias	Malian Govt	FPR
MNLA		1	-1	-1	-1	-1	-1
AAD			-1	-1		-1	-1
AQIM				1		-1	-1
MUJAO						-1	-1
Arab Militias						-1	-1
Malian Govt							1
FPR							
3 Subsets, 0 Inconsistencies							

	MNLA	AAD	AQIM	MUJAO	Arab Militias	Malian Govt	FPR
MNLA		1	-1	-1	-1	-1	-1
AAD			-1	-1		-1	-1
AQIM				1		-1	-1
MUJAO						-1	-1
Arab Militias						-1	-1
Malian Govt							1
FPR							
4 Subsets, 0 Inconsistencies							
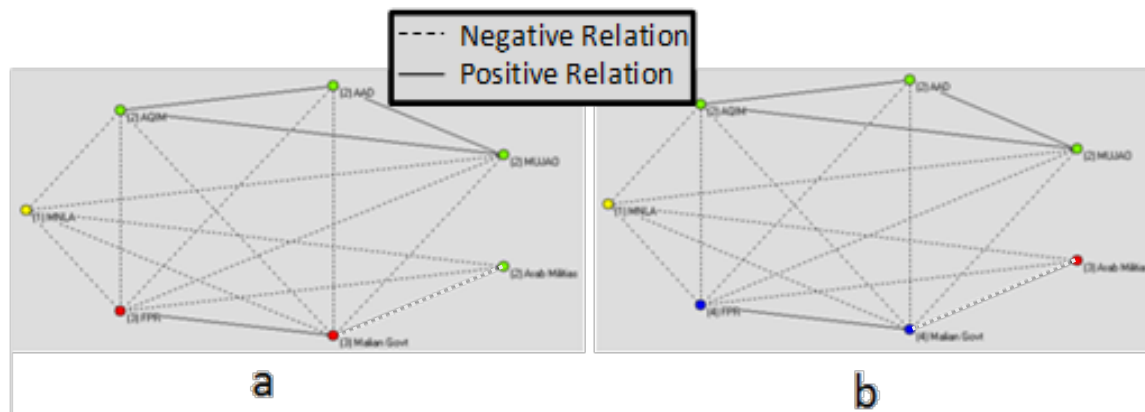
Figure 20: Balanced blockmodels and graphs if the two relationships under the most tension (AAD/MNLA and Arab Militas/Mali government) were influenced to change. (Matrices are symmetric)

After the previous analysis was conducted, on 23 January 2013, AAD effectively split. The splinter group, the Islamic Movement for Azawad (IMA), led by an important tribal leader, Algabass Ag Intallah, renounced terrorism and extremism in favor of a negotiated peace to the Mali conflict (Beaumont, 2013). The goal of IMA is to set up an autonomous region in Northern Mali, as opposed the MNLA's initial goal of complete independence. The establishment of this group is an indication of the pressure the

AAD/MNLA relationship was under to change. This model identified the tension within this relationship. While the model does not predict what actions the actors would take, it did suggest the relationship merited further analysis. In this case, the group splintered creating new relational dynamics. Chapter Five observes these changes and analyzes in more detail the actors and relationships of the conflict following French and African forces involvement and the creation of the IMA.

4.5.2   Relaxed Blockmodeling.

When Relaxed Blockmodeling is conducted on the same network of seven actors, it is subdivided into five subsets with no inconsistencies. See Figure 21 for the network graph and Figure 22 for the relaxed fit image matrix showing the subsets and relations of the relaxed fit. In this partitioning, AQIM and MUJAO are grouped together because they have the same ties to all other actors and like each other. In addition, FPR and the Arab Militias are grouped. This grouping is contradictory to social balance theory (negative block on the diagonal) but is allowed with the relaxed rules. This grouping makes sense because they have the same relations with all common actors and mutually dislike each other. When a relaxed blockmodel has zero inconsistencies and there are no negative blocks on the diagonal, then the graph can be reduced to the identified subsets without losing any information. However, when there is a negative block on the diagonal, the actors in the diagonal negative block have the same relations to all other actors, but dislike each other. Therefore, if those actors are clustered into the same group to reduce the graph, the internal relationship between actors in that

node needs to be kept track of as negative. For example, the seven actor network can be reduced to a five actor network as identified in the relaxed blockmodel. However, the FPR/Arab Militias grouping would be a negative node since they do not like each other, but have the same relation to all others. This demonstrates that despite the historic ethnic tension between the two groups, they actually have common friends and enemies. This suggests that there may be a basis for cooperation and mutual understanding between these two historic rivals.
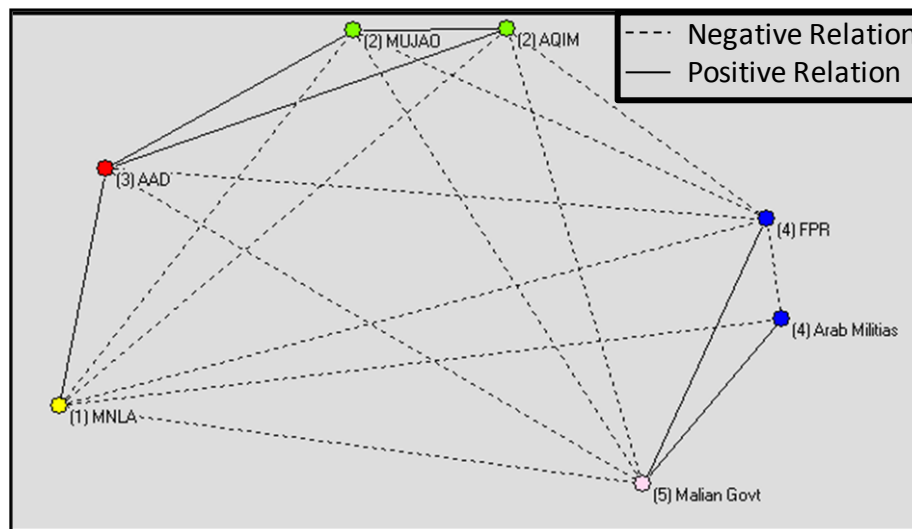
Figure 21: Network graph showing the five subsets found by the Relaxed Blockmodeling method. By author using Pajek (Batagelj & Mrvar, 1996).
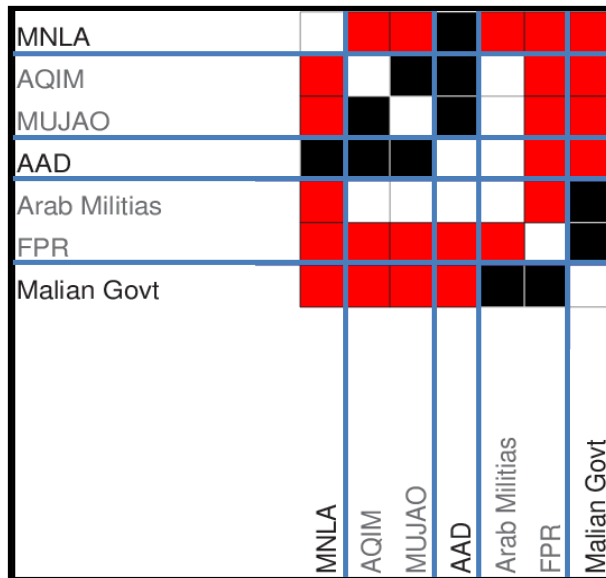
Figure 22: Image matrix blockmodeling the seven militant groups into five subsets. Red is negative and black is positive. By author using Pajek (Batagelj & Mrvar, 1996).

A mediator can be identified when Relaxed Blockmodeling has a negative block on the diagonal and zero inconsistencies. The mediator is identified by finding a positive block horizontal or vertical to the negative diagonal block. In the current example, the Malian government affiliated forces have a positive block horizontal and vertical to the negative diagonal block. The Malian government makes sense as a mediator since both the FPR and the Arab militias have a positive relation with Malian government affiliated forces, but dislike each other.

4.6   Additional Social Network Analysis

As discussed in 2.9, other metrics can be used to provide insight on the composition of signed networks. Three of the most useful metrics to evaluating signed networks are the popularity measure of likes minus dislikes, ratio of likes over total

relations and eigenvector centrality. Likes minus dislikes is a quick snapshot of the

network by measuring each actor's popularity within the network. Popularity of an

actor in a signed network can be a useful measurement because a more popular actor is

assumed to have more influence within the network.   The likes minus dislike values and

the ratio of number of likes over total relations for the Malian groups are in Table 8. A

negative value in the likes minus dislikes column means that the actor is disliked more

than they are liked. Positive means they have more friends than enemies. The FPR and

MNLA have the lowest popularity and AAD has the highest. This puts AAD in a position

where they have more influence throughout the network than any other group.

Observe that the top three like minus dislike rankings are the three Islamist groups. One

must look back to the network to determine why these groups are the highest. These

groups have almost identical relationships to the rest of the network (AQIM and MUJAO

are identical) while the rest of the actors in the network have unique relationships. This

suggests that the Islamists are much more united than the other groups. This result is

expected based on the extremist groups working together to control Northern Mali,

while the remaining actors have various negative relations between them.

Table 8: Popularity measures of actors: Likes minus Dislikes and Ratio of Likes/Total relations (sorted from highest to lowest)

Militant Group	Likes minus Dislikes	Ratio: # Likes over Total Relations
AAD	1	0.6
AQIM	-1	0.4
MUJAO	-1	0.4
Arab Militias	-1	0.333
Malian Govt	-2	0.333
FPR	-4	0.167
MNLA	-4	0.167

Eigenvector centrality is another measure of popularity that considers additional details of a network than just an actor's first hand relationships. An actor's centrality value will increase by having a positive connection to a high status actor or a negative connection to a low status actor. Likewise, an actor's centrality will decrease if it has a negative connection to a high status actor or a positive connection to a low status actor. The eigenvector centralities for the Malian groups are in Table 9.

Table 9: Eigenvector Centrality (sorted from highest to lowest). Calculations by author using UCINET (Borgatti, Everett, & Freeman, 2002)

Militant Group	Eigenvector Centrality
AAD	0.465
AQIM	0.404
MUJAO	0.404
MNLA	0.154
Arab Militias	-0.042
FPR	-0.456
Malian Govt	-0.473

Notice that the top three highest rated groups are the same as in Table 8 and Arab militias and FPR are in roughly the same position as well. The MNLA, which had

the worst like minus dislike rating, has a positive value for eigenvector centrality. The

MNLA benefits from its positive relation to the most central actor (AAD) and its negative

relations to the two least central actors (FPR and Malian Govt). The Malian government

militias' popularity changed in the two measurements as well. Its popularity is effected

both by liking lower groups and disliking the higher groups. One interesting thing to

note is that the eigenvector centrality rankings, when grouped, will provide the same

partition as identified via structural balance theory and depicted in Figure 20b; {AAD,

AQIM, MUJAO}, {MNLA}, {Arab Militias}, and {FPR, Malian Govt}.

The techniques in this section identify ways to assess individual actors within the

network. Each actor can be compared to the rest of the network to gauge their

popularity. Popularity can be an indication for how influential an actor is. In all three

measurements AAD was the most popular actor. This observation provides an

indication for why AAD has been growing both in numbers and power throughout

Northern Mali during the last half of 2012. Fighters were leaving MNLA and the FPR and

joining AAD based on the power and influence the group wielded (Boisvert, 2012)

(Jamestown Foundation, 2012).

4.7 Chapter Summary and Conclusions

Using the militant groups in Mali as an example, this chapter demonstrates the

methodology of partitioning and evaluating signed social networks. The model

identifies four different partitions out of 877 that provide the best depiction of how the

groups are interrelated. This methodology allows intelligence analysts the ability to

focus in on these specific partitions in order to analyze inconsistencies within the network. It also suggests potential influence targets. Inconsistencies can potentially identify errors in classification of a relationship or identify relationships that are vulnerable to change. The relationship that the model found that was most likely to change in this illustration was the AAD/MNLA relationship. The recent splitting of AAD into two groups, demonstrates the model identified a relationship that was under tension and had a high likelihood of changing. In the next chapter new actors are introduced to the model and the relationships are identified based on more current events. The new network is then evaluated using the same methodology to draw conclusions about the actors and their relationships in the new Malian operating environment.

5 Mali Militant Groups Case Study Post-French Intervention

5.1 Introduction

The previous chapter delineated key actors participating in the conflict in Northern Mali prior to 11 January 2013. This chapter provides a second illustrative example to explain how the methodology could be used to decompose and begin to comprehend a complex relational situation. This example considers the relations of key actors in Northern Mali over the period of 11 January to 11 February. The two models are then compared in Chapter Six where conclusions and recommendations are presented on the methodology and future work.

In the beginning of January, the Islamic extremist forces began moving south, out of the desert region, into Southern Mali. The provisional Malian government, unable to stop the militants themselves, asked France for support. The French entered Mali on 11 January and, after initial loses, began defeating the extremists. By February all of the main cities of Northern Mali were regained by Malian, French and other forces. Other than France, the international ground forces are from African nations supported by the Economic Community of West African States (ECOWAS) and the operation is classified by the United Nations as the African-led International Support Mission in Mali (AFISMA). The other major addition to the key actors from the model in Chapter Four is the creation of the Islamic Movement for Azawad (IMA). The IMA has split off of Ansar Al-Din and created a separate organization. This chapter adds the three new actors (French forces, ECOWAS forces, and the IMA) to the model from Chapter Four to assess

how the intervention has affected the structural balance of key actors within Northern

Mali. Modeling the actors in this way enables analysts to identify the cliques and

subsets within a network, relations vulnerable to change, and potential mediators

between subsets.

5.2   Key Actors

This study explores the relations between ten actors (three new actors and

seven original actors) evaluated in the Chapter Four model. With the involvement of

French and ECOWAS forces as well as the establishment of a new group, the IMA, this

model is expanded to address the added complexity of the situation. The ten key actors

are listed in Table 10. Arab militias and Patriotic Forces of Resistance (FPR), from the

Chapter Four model, are included in this revised model as well. The Arab militias seem

to be maintaining a low profile. Very little open source information is currently being

released on their involvement in the conflict. Therefore the only relationships that are

assessed on the Arab militias are their cultural and historic negative relations between

themselves and the MNLA and FPR. The FPR relations are assessed to be exactly the

same as the Malian government, as their goals are to defeat the rebellion and support

the government. The relations of the other actors are discussed in subsections 5.2.1

through 5.2.6. An overview of all actors is displayed in Table 10.

Table 10: Key Actors of Post-French Intervention in Mali

Number	Group	Ideology	Goal	Ethnicity	Area of Operation	Like	Dislike
1	MNLA	Secular	A secular, independent government in Azawad	Primarily Tuareg	Kidal	3,8,9	2,4,5,6,7
2	AQIM	Extreme Islamic	Establish an Islamic Caliphate throughout Muslim world	Algerian leadership, African participants	Timbuktu/ Dispersed across Northern Mali	3,4	1,6,7,8,9,10
3	AAD	Extreme Islamic	Establish an Islamic State of Mali with	Primarily Tuareg leaders, other ethnic participants	Kidal/Timbuktu	1,2,4,10	6,7,8,9
4	MUJAO	Extreme Islamic	Establish an Islamic Caliphate throughout Muslim world	Mauritanian leader, African participants	Gao/Menaka	2,3	1,6,7,8,9,10
5	Arab Militias	Islamic	Defend and protect there own interests	Arab	Lere/Timbuktu	6	1,7
6	Malian Govt	Secular	Regain control of their territory and defeat the rebel movement	Bambara, Peuhl, Senufo, Songhai, Dogon, Malinke and others	Mopti, Sevare	5,7,8,9	1,2,3,4,10
7	FPR	Secular	Regain control of lost Mali territory and defeat the rebel movement/Revenge	Songhai, Peuhl, Bozo, Bella and others	Originally Gao and Douentza, moved south when Islamists took over	6,8,9	1,2,3,4,5,10
8	French Forces	Secular	Reduce the terrorist threat in the region/Regain Mali's sovereign territory	French	All of Mali	1,6,7,9,10	2,3,4
9	ECOWAS Forces	Secular	Reduce the terrorist threat in the region/Regain Mali's sovereign territory	African	All of Mali	1,6,7,8,10	2,3,4
10	IMA	Islamic	An Islamic Autonomous region in Northern Mali	Primarily Tuareg	Kidal	1,3,8,9	2,4,6,7

5.2.1 National Movement for the Liberation of Azawad (MNLA).

With the French and Malian military success in Northern Mali, the once marginalized MNLA has once again become a key player within the Tuareg community. They maintain the same relations with the previous actors, disliking AQIM and MUJAO for terror and extremist reasons, Arab militias and FPR for cultural and historic reasons, and the Malian military due to a long history of conflict and distrust. The MNLA continue to have a complicated relationship with AAD. This study still classifies the

relationship as positive due to the Tuareg ties between the organizations, but the segmenting of the moderate IMA's from AAD has resulted in a weaker connection between the MNLA and AAD. The MNLA has positive ties with the three new actors in the model. As the AFISMA forces regained control of the cities in Northern Mali, the MNLA allowed the French to enter, but told the Malian military to stay out of the city of Kidal (Harding, 2013b). The IMA, like the MNLA, is a Tuareg organization and is likely to maintain close ties, at least at the leadership level, with the MNLA. The ideological difference between the two organizations is that the MNLA is secular and the IMA is Islamic. Both groups appear to be now seeking an autonomous Northern region of Mali as opposed to the MNLA's original goal of independence.

5.2.2   Al-Qa'ida in the Islamic Maghreb (AQIM) and the Movement for Oneness and Jihad in W. Africa (MUJAO).

AQIM and MUJAO maintain the same relations with all of the same actors that were in the seven actor model of Chapter Four. Both groups like AAD and dislike all other actors. The new actors are all disliked by AQIM and MUJAO because the international forces have become involved in the conflict to defeat these terror organizations. The IMA has renounced terrorism and may even be willing to fight against these organizations (Beaumont, 2013).

5.2.3   Ansar Al-Din (AAD).

As of mid-February, Ansar Al-Din has continued to hold fast to its extreme Islamist ideology. As a result, more moderate members of the organization broke off

from the group to form the IMA. This demonstrates Ansar Al-Din's power and prestige

with the population of Northern Mali has suffered as the AFISMA forces took control of

the populated areas. AAD is still closely aligned with AQIM and MUJAO. The strong

Tuareg ties between AAD, IMA and MNLA result in this study classifying these

relationships as positive. AAD has negative ties to the French, ECOWAS, FPR and Malian

government. The AAD relationship with the Arab militias is not known and is therefore

classified as null.

5.2.4   Mali Government Forces.

The Malian government forces are still very weak and vulnerable. While some

Malian forces are assisting the French in the North, on 8 February in the capital, Malian

troops were fighting each other. The old presidential guard, still loyal to the overthrown

president, was attacked by the unelected interim government forces (Harding, 2013a).

In a time where their country is being assisted by foreign forces, the Malian army is

unable to put aside their differences to participate fully in the fighting against the

enemy. This infighting and complications between Malian army units demonstrates the

difficulties of classifying relationships as a whole. While the infighting suggests the

potential for future difficulties, this study assumes the Malian army is loyal to the

interim government and supporting the AFISMA forces in deposing the Islamic

extremists from control of Northern Mali. Mali forces have positive relations with the

French forces, ECOWAS forces and the FPR. Due to ethnic and historical reasons, the

Malian army has negative relations with MNLA and IMA. It has negative relations with

AQIM, MUJAO and AAD as evidenced by the fighting taking place to remove the extremists from the country. It is unknown how the Malian forces interact with the Arab militias, therefore that relationship is classified as null.

5.2.5 African-led International Support Mission in Mali (AFISMA).

The African-led International Support Mission in Mali (AFISMA) is the combined international forces operating in Mali. This mission was authorized by the United Nations in December 2012 and initiated in January when the French intervened in Northern Mali (February 2013 UN Monthly Forecast - Mali). The French have repeatedly stated they want to turn the entire operation over to African forces to oversee a peacekeeping operation. A United Nations sanctioned peacekeeping mission could additionally be authorized to further support the international effort in Mali. The AFISMA forces have favorable relations with the Malian government forces, the FPR, the MNLA and the IMA. The MNLA and presumably the IMA have been supporting the international forces in Kidal and other strongholds against extremist forces. AFISMA has negative relations with AAD, AQIM, and MUJAO. Their relation with the Arab militias is unknown at this time and is therefore classified as null.

5.2.6 Islamic Movement for Azawad (IMA).

The Islamic Movement for Azawad (IMA) is a splinter organization from Ansar Al-Din. Led by an important Tuareg tribal leader, Algabass Ag Intallah, they have renounced terrorism and extremism in favor of a negotiated peace to the Mali conflict (Beaumont, 2013). The stated goal of the IMA is to set up an autonomous region in

Northern Mali with a moderate Islamic government. Many of the Tuareg who

participated with Ansar Al-Din were not known to be overly religious prior to joining the

organization. These moderates were willing to support Ansar Al-Din while AAD had

increased power and influence throughout the later part of 2012. Once the French

forces began defeating the Islamic extremists, the moderates of AAD saw a way out of

the extremist organization that AAD had become, leading to the creation of IMA. The

IMA have the same relations as the MNLA. They like AAD, the French, and the ECOWAS

forces and dislike all other actors.

5.3   Assessing Relationships between Actors

The previously identified groups and their relationships provide the basis for the

analysis in the next two sections. The relations between these groups are shown in the

matrix in Table 11 and the network graph in Figure 23 are based on the observations

presented in sections 4.3 and 5.2. It should be noted that the relationships in this

illustrative example are the assessment of the author, based on open source literature.

Actual relationship values should be reviewed and updated by regional, cultural and

subject matter experts.

Table 11: Mali Actor's Relationship Matrix (Post-French Intervention)

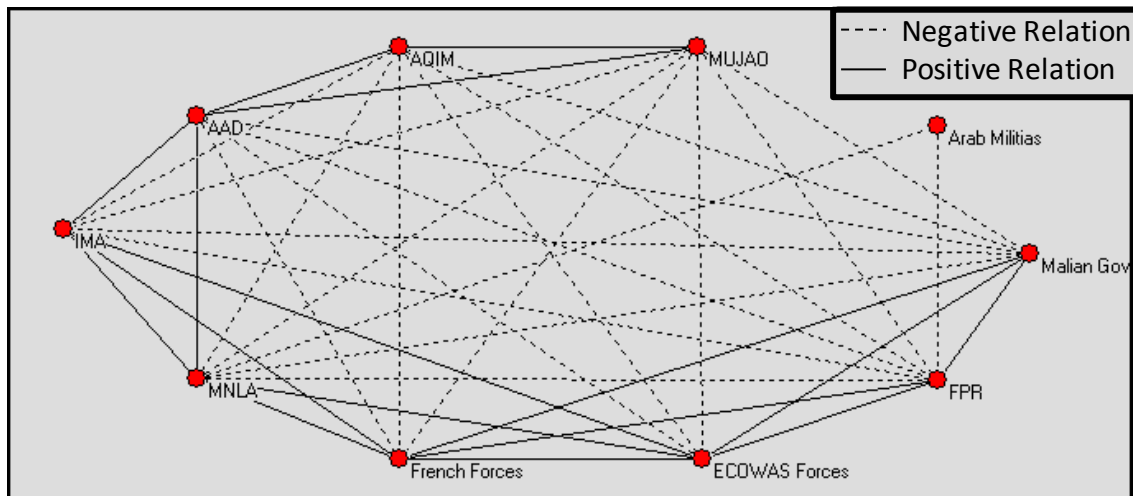|	MNLA	AQIM	AAD	MUJAO	Arab Militias	Malian Govt Forces	FPR	IMA	French Forces	ECOWAS Forces
MNLA		-1	1	-1	-1	-1	-1	1	1	1
AQIM	-1		1	1		-1	-1	-1	-1	-1
AAD	1	1		1		-1	-1	1	-1	-1
MUJAO	-1	1	1			-1	-1	-1	-1	-1
Arab Militias	-1					-1	-1			
Malian Govt Forces	-1	-1	-1	-1			1	-1	1	1
FPR	-1	-1	-1	-1	-1	1		-1	1	1
IMA	1	-1	1	-1	-1	-1	-1			1
French Forces	1	-1	-1	-1		1	1	1		1
ECOWAS Forces	1	-1	-1	-1		1	1	1	1	

Figure 23: Network Graph of 10 Actor Network (Post-French Intervention)
Graph by author using Pajek (Batagelj & Mrvar, 1996)

5.4   Partitioning Actors into Subsets

5.4.1   Generalized Blockmodeling

As the number of actors in a network increases, the network graph can begin to appear cluttered and illegible, clouding the ability of an analyst to make any conclusions. It is precisely this problem that this thesis is designed to address. With ten actors, there are 115,929 different partitions possible. Using the relocation method and generalized blockmodeling, Table 12 identifies the minimum number of inconsistencies and the number of different subsets with that minimum number of inconsistencies.

Table 12: Minimum Inconsistencies for 10 Actor Model using Relocation Method

# of subsets	1	2	3	4	5	6	7	8	9	10
Minimum # of Inconsistencies (Criterion Function)	22	6	6	6	7	9	10	13	15	16
# of possible different subsets with Minimum # of Inconsistencies	1	1	4	3	3	10	2	10	16	1

In this network, the minimum number of inconsistencies in a partition is six. There are six inconsistencies when the network is partitioned into two, three and four partitions. When partitioned into two, there is one way to partition the network to get six inconsistencies. There are four ways to partition into three subsets and three ways to partition into four subsets to get six inconsistencies. Therefore there are eight partitions identified that have the minimum number of inconsistencies. These eight partitions should be evaluated in closer detail to determine which of them best represent the real world situation. In each of these eight situations there are six relations that do not support social balance theory. See Figure 24 for the network graphs of the eight different partitions identified.
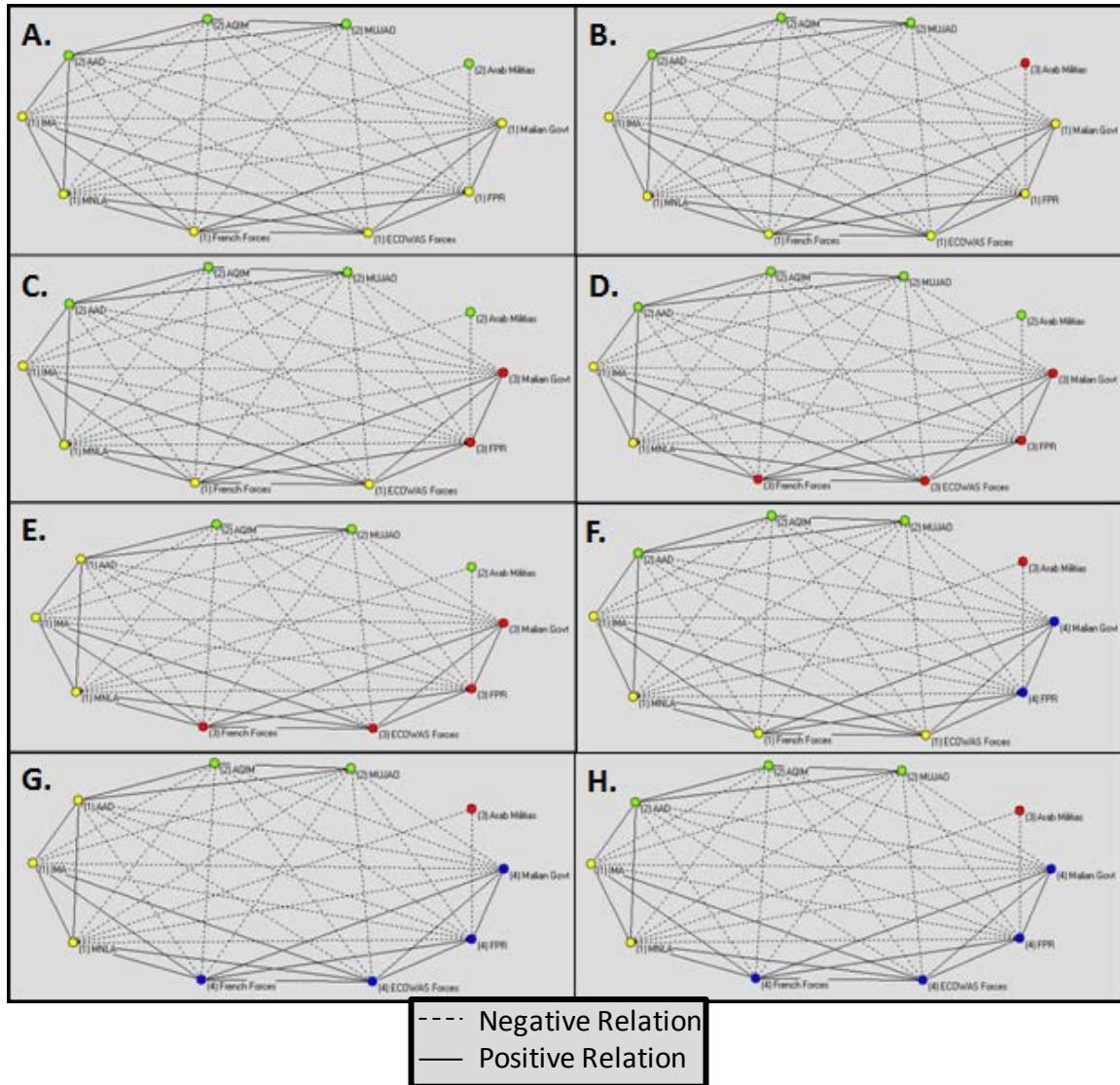
Figure 24: The graphs for the eight different partitions with six inconsistencies for the ten actor network. Graph A is partitioned into two subsets. Graphs B, C, D, and E are partitioned into three subsets. Graphs F, G, and H are partitioned into four subsets. Graph by author using Pajek (Batagelj & Mrvar, 1996)

The number of times a relationship over all the partitions in Figure 24 is computed. The relationships that are identified as inconsistent the most often are the ones that are responsible for the tension in the network as it is currently defined. As shown in Table 13, the MNLA/AAD and IMA/AAD relations are inconsistent in six out of

the eight blockmodels. These relations should be reanalyzed to determine if they are correctly observed or if there is unusually high tension for them to change. These relations are under stress, but the MNLA and the IMA have clearly stated their disapproval of the terror and extremism that AAD endorses. However, these groups are all Tuareg and it is difficult to consider their relations negative despite the current tension and opposing alliances. These relationships identify AAD as the link between Tuareg organizations and the Islamic extremists.

The next relationships that appear often are the MNLA and IMA's relations with the French and ECOWAS forces. These relations are identified as inconsistent half of the time. When considered with the previous inconsistencies of the MNLA and IMA's relations with AAD, it is obvious that the MNLA and IMA are being pulled in two different directions. Either they align with the international forces or they align with AAD. The MNLA and IMA appear to have the option to be the mediator between the two groups or join one of them and oppose the other. As conditions exist in mid-February, the MNLA and IMA appear to be taking the mediator approach. They want to be included by the international forces in any agreement and shaping of the future of Northern Mali. Since an outright alliance with AAD at this time means being allied with AQIM and MUJAO, the MNLA and IMA are unlikely to increase ties to AAD at this time. However, the existing cultural ties between the Tuareg in MNLA, IMA, and AAD will not disappear and need to be monitored as the situation changes. It is likely that

individuals, both leaders and fighters, will flow between the organizations as one or

another organization gains power and influence.

Table 13: Number of inconsistencies by relationship occurring in the eight identified minimum inconsistency blockmodels from the 10 actor network.

Relationship	# of times relationship was an inconsistency out of 8 blockmodels
MNLA/AAD	6
IMA/AAD	6
MNLA/ECOWAS	4
IMA/ECOWAS	4
MNLA/French	4
IMA/French	4
MNLA/Mali Govt	2
IMA/Mali Govt	2
MNLA/FPR	2
IMA/FPR	2
FPR/French	2
FPR/ECOWAS	2
Mali Govt/ French	2
Mali Govt/ ECOWAS	2
AQIM/AAD	2
MUJAO/AAD	2

5.4.2   Relaxed Blockmodeling

Since there are such a high number of minimum inconsistencies, relaxed

blockmodeling should be conducted to investigate if a better partitioning can be found

when constraints are relaxed. When Relaxed Blockmodeling is conducted on the ten

actor network, the network can be partitioned into five groups with no inconsistencies.

Table 14 provides the minimum inconsistencies for the 10 actor network using Relaxed Blockmodeling.

Table 14: Minimum Inconsistencies for 10 Actor Model using relaxed blockmodeling

# of subsets	1	2	3	4	5	6	7	8	9	10
Min # of Inconsistencies via Relaxed Generalized Blockmodeling	16	6	4	2	0	0	0	0	0	0
# of possible different subsets with Minimum # of Inconsistencies	1	1	2	1	1	8	19	19	9	10

This method identifies zero inconsistencies when the network is partitioned into five subsets.   See Figure 25 for the relaxed blockmodel and Figure 26 for the network graph of the ten actor network with five subsets.
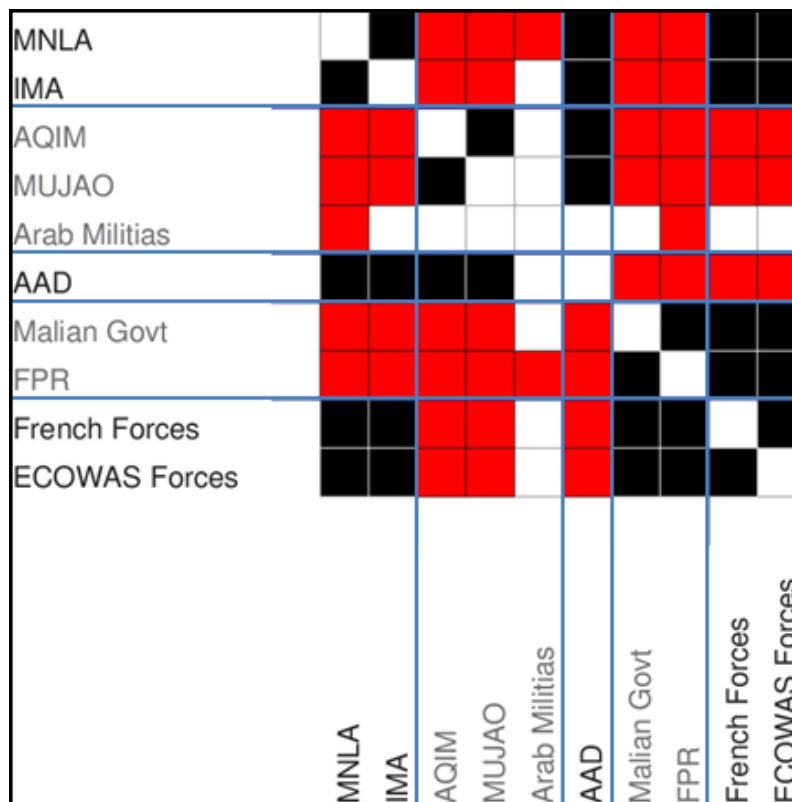

Figure 25: Relaxed Generalized Blockmodel for the ten actor network partitioned into five subsets with zero inconsistencies.
Graph by author using Pajek (Batagelj & Mrvar, 1996)
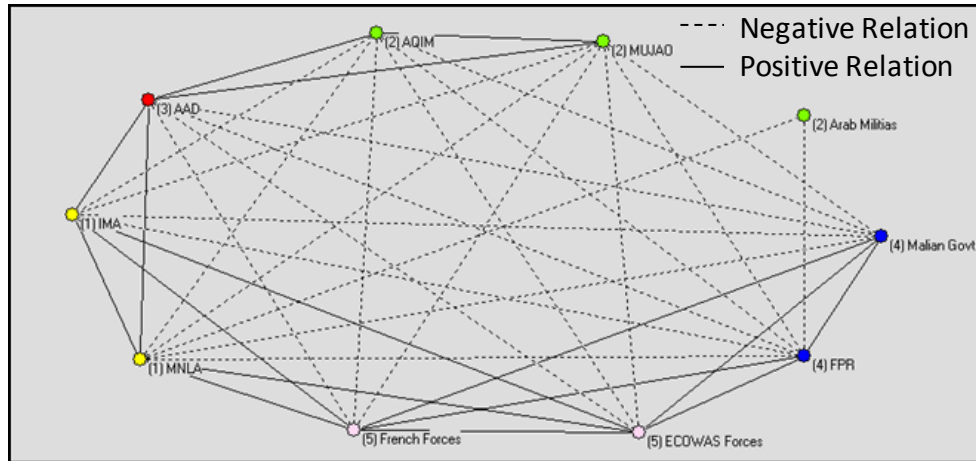
Figure 26: Network graph of ten actor network partitioned based on the Relaxed Blockmodeling method.
Graph by author using Pajek (Batagelj & Mrvar, 1996)

Since there are no negative blocks on the diagonal and zero inconsistencies, the network can be reduced without losing any information. By partitioning into the five subsets identified by relaxed blockmodeling, the graph is reduced from 10 nodes to five nodes, resulting in a simplified network. This smaller network allows for quicker calculations and easier to understand observations. The reduced network is shown in Figure 27.
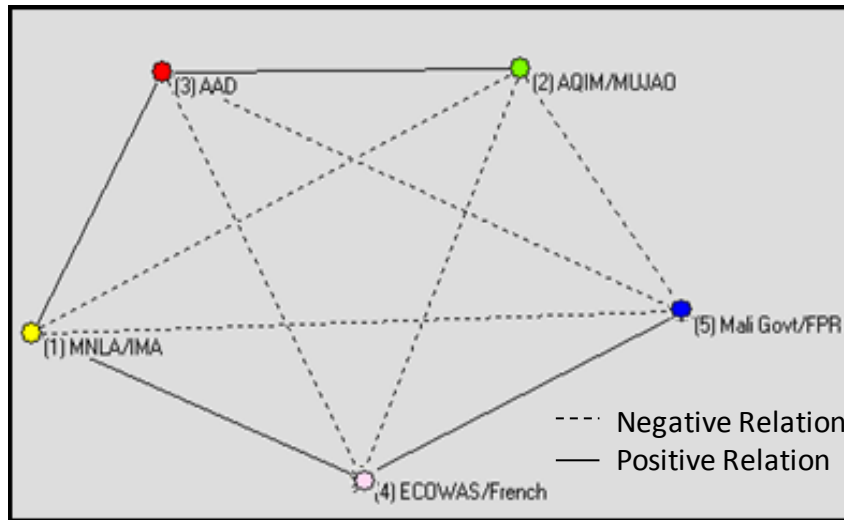
Figure 27: Reduced Network graph from ten nodes to five nodes.
Graph by author using Pajek (Batagelj & Mrvar, 1996)

The reduced network allows for some simple observations to be made. First, it shows AQIM/MUJAO and Mali Government/FPR each have one positive relationship. Additionally, it shows the other three subsets each have two positive relationships. Any of the actors that have two positive connections could be considered mediators between the subsets they connect. For example, if the French wanted to negotiate or pass a message to the Ansar Al-Din group, it is likely they could do this through MNLA or IMA and vice versa.

If the reduced network identified by Relaxed Blockmodeling is analyzed for structural balance, five different partitions can be identified with the minimum number of inconsistencies of two, see Table 15.

Table 15: Minimum Inconsistencies Identified by the Reduced Network

# of subsets	1	2	3	4	5
Minimum # of Inconsistencies (Criterion Function)	6	2	2	3	4
# of possible different subsets with Minimum # of Inconsistencies	1	2	3	4	1
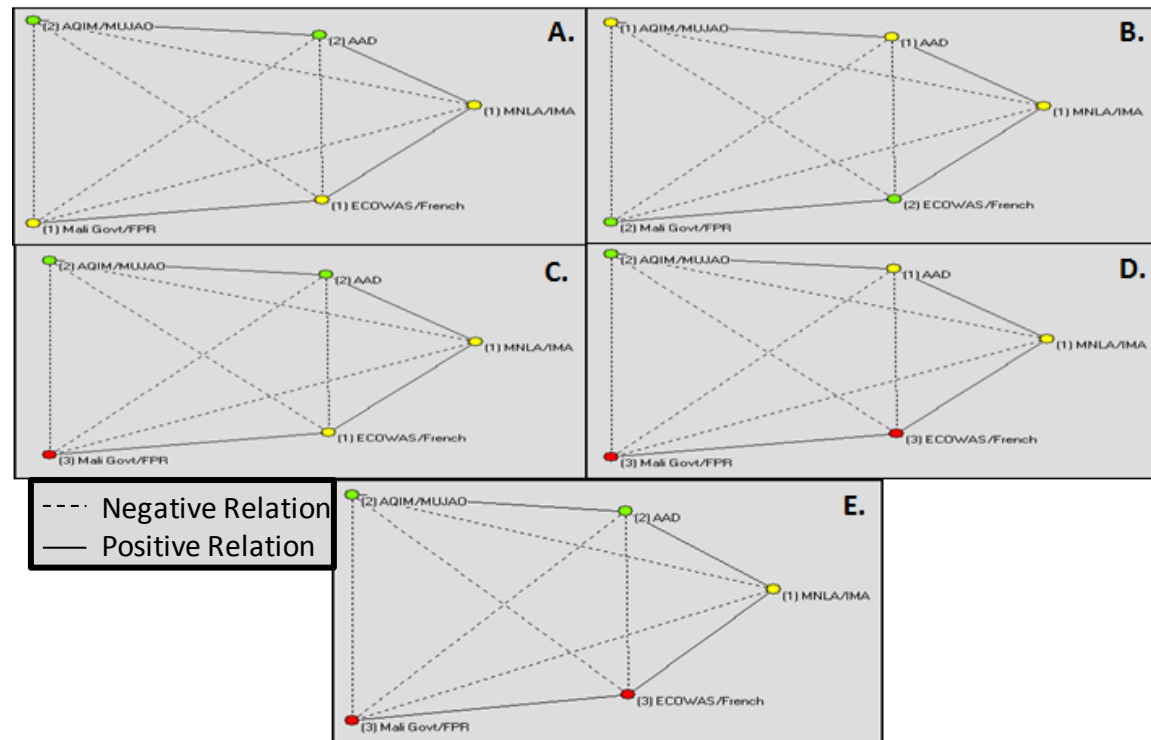
Figure 28: Five different partitions of the reduced network, each having two inconsistencies. Graphs A and B are partitioned into two subsets, Graphs C, D, and E are partitioned into three subsets.
Graph by author using Pajek (Batagelj & Mrvar, 1996)

The five different partitions of the reduced network are simplifications of the eight

different partitions identified in the full network. There are five partitions instead of

eight because the Arab Militant groups have been combined with AQIM and MUJAO and

cannot be partitioned into their own subset after being combined. In looking at the five

different subsets, A and E seem to be the best partitions based on what is happening in

Mali. Partition A may make sense for the initial phases of the foreign intervention. The

MNLA and IMA have supported the international forces and have even captured high profile members of MUJAO and AAD (Ramzi, 2013), leading one to believe they should be in the group with the International and Malian forces. However, partition E may be a better long-term partition of the reduced network because the MNLA/IMA will work with international forces, but may not work with Malian forces due to mutual distrust. The AFISMA forces are in Mali to assist the government, therefore their first loyalty must be to the government forces, making E a more logical partition.

There are three unbalanced triads in each of the partitions in Figure 28, all have two positive and one negative relation. AQIM/MUJAO, AAD, and MNLA/IMA are one triad, AAD, MNLA/IMA, ECOWAS/French is another, and Mali government/FPR, ECOWAS/French, and MNLA/IMA is the third. These types of unbalanced triads can become balanced by the negative relation turning positive or one of the positive relations turning negative. Essentially if any relation in the triad changes, it becomes balanced. While these triads remain unbalanced there is tension between the three actors involved. The only actor involved in more than one unbalanced triad is MNLA/IMA; therefore they are under the most pressure to change their relations. However, this also puts them in a position to mediate between the two major subsets, once again making partition E the likely partition for the post-French intervention network.

Assuming that partition E is the best partition for the real-life situation in Mali and that no additional key actors will enter the network, there are three options to

make partition E balanced. The MNLA/IMA is shown as a mediator between the two larger groups; the Islamic militants on the top part of the graph and the International forces on the bottom. MNLA/IMA can create a balanced network by making their relations to both AAD and ECOWAS/French negative (isolating themselves), they can make their relation negative to ECOWAS/French and positive to AQIM/MUJAO (joining the Islamic groups), or they could make their relation negative to AAD and positive to Mali government/FPR (joining the International forces). Contrary to social balance, the author does not foresee any of these changes taking place. Instead, the MNLA/IMA is likely to try to enhance its role as mediator between the groups and strengthen its position as an intermediary. Acting in this role provides the MNLA/IMA with influence and control over negotiations and governance. Therefore tension within the network is likely to continue.

5.5   Additional Social Network Analysis

Just as was done in section 4.6, the popularity measures likes minus dislikes, a ratio of likes over total relations, and eigenvector centrality are used to evaluate the ten actor signed network. Recall that these are different popularity measures. Likes minus dislikes counts the number of positive and negative relations each actor has and subtracts them. The ratio measure divides the positive relations by the total relations to provide a percentage of friends for each actor. The actors with higher, more positive values are more popular. The values are listed in Table 16. Although these measures do not take into account the strength of the actors, it does provide an indication of the

popularity of the actors based on the actors included in the model. The larger a

network is, the less susceptible the likes minus dislikes and ratio of likes measurements

are to actors omitted from the model. If the assumption is valid that the more popular

an actor is, the more influence they have on the network, then the actors that score

higher on pure popularity measures (likes minus dislikes and ratio of likes) are the most

influential within a network. Since these two measures do not take into account who

the relationship is with, as eigenvector centrality does, the actors that score high on

these measurements can influence the most actors. Alternatively, eigenvector

centrality identifies the actors that influence the most popular actors.

**Table 16: Popularity measures of actors (Post-French Intervention): Likes minus
Dislikes and Ratio of Likes/Total relations (sorted from highest to lowest)**

Militant Group	Likes minus Dislikes	Ratio: # Likes over Total Relations
French Forces	2	0.63
ECOWAS Forces	2	0.63
AAD	0	0.50
IMA	0	0.50
MNLA	-1	0.44
Malian Govt Forces	-2	0.38
Arab Militias	-2	0.00
FPR	-3	0.33
AQIM	-4	0.25
MUJAO	-4	0.25

When comparing the popularity of individual actors in Table 16 to the same actors in Table 8, the Pre-French intervention network, the results seem to be reversed. Instead of the Islamic groups being the most popular, they have become the least popular. This makes sense since all three of the new actors added to the model are anti-Islamic extremists. The exception to this is AAD. AAD is surprisingly still popular according to these measures even though they are most associated with the two least popular groups.

Eigenvector centrality calculates an increase in popularity of an actor if they have a positive relation to a popular actor or a negative relation to an unpopular actor and a decrease if they have a negative relation to a popular actor or a positive relation to an unpopular actor. Eigenvector centrality of the ten actor network is shown in Table 17.

Table 17: Eigenvector Centrality of actors (Post-French Intervention)

Militant Group	Eigenvector Centrality
French Forces	0.398
ECOWAS Forces	0.398
FPR	0.339
Malian Govt Forces	0.328
MNLA	0.129
IMA	0.118
Arab Militias	-0.076
AAD	-0.28
AQIM	-0.398
MUJAO	-0.398

The order of Table 17 is similar to Table 16 except AAD and FPR have flip-flopped

positions. This is because FPR is positively connected to the most popular actors and

negatively connected to the most unpopular actors while AAD is positively connected to

the most unpopular actors and negatively connected to the most popular actors. The

eigenvector centrality rankings, when grouped, provide the same partition as identified

via the partition we identified in Figure 28E. At least according to these two illustrative

examples, the eigenvector centrality measure provides not only a popularity measure

but also a potential partitioning of the actors. More analysis should be conducted to

determine if this is the case in other types of examples. The approach outlined here,

however, does suggest an area to focus future research efforts.

5.6   Chapter Summary and Conclusions

Taking the influential militant actors in Northern Mali from 11 January to 11

February 2013 as an example; this chapter analyzes the positive and negative relations

and makes some observations about the subsets and mediators within the network.

Additionally, specific relations are identified as causing tension to the network based on

social balance theory. Generalized blockmodeling found eight out of 115,929 possible

partitions that minimized the inconsistencies in the network according to social balance

theory. Relaxed Blockmodeling was then used to reduce the network from ten actors to

five. These five actors were blockmodeled a second time finding five partitions that

minimized the inconsistencies. These five partitions were analyzed to determine the

most likely partition to fit the example. It was determined that there are likely two main

subsets, the Islamic extremists and the International forces. Additionally, the

MNLA/IMA were found to be the probable mediators between the two subsets.

Popularity measures were calculated to identify influential actors within the network.

These measures found the popular actors from Chapter Four (the Islamic extremists)

were not popular in this network and the unpopular actors became much more popular

due to the inclusion of the additional actors.

6   Findings and Conclusion

6.1   Introduction

This chapter summarizes the overall contributions of the research methodology to the operational and academic communities, reiterates the results of the research from Chapters Four and Five, and presents recommendations for future research.

6.2   Contributions of the Research

This research provides a methodology to analyze signed networks based on social balance theory. It identifies a way to partition a signed network to identify likely subsets within the network. Unique actors and relationships are pinpointed based on inconsistencies or imbalances within the network. Inconsistent relationships are more likely to change than other relationships because there is increased tension between the actors involved. Identifying this tension provides analysts with insight into the complexities of the network and potential relationships in which to influence. These relationships can be targeted to stabilize or destabilize a network.

The model can be used by analysts to analyze an array of different real world situations. For example, if data is available on like/dislike tribal relations in a region of interest, this model could aid in identifying the sources of tension within that area of operations as well as the popularity of the actors, identification of allied groups, and the actors that can mediate between those groups. Another possible application is the militia groups currently operating in Libya. Since only some are friendly to the

government and all have varying feelings toward each other, these relationships could be modeled to gain additional insights into the web of relationships. A third application is the complex relations of the different opposition groups operating within Syria. These groups are disjoint and have competing goals and ideologies, making the network difficult to dissect without this methodology.

Another interesting application would be to assess the relations between the international forces assisting in Mali. All of the different countries providing troops may have conflicting relations between each other and the local population. Positive and negative relations need to be considered in any type of international humanitarian or support mission. In whatever application, increased knowledge about how these groups relate to each other can provide important information to aid U.S. decision making within a region of interest.

6.3   Results of the Research

The two illustrative examples provided in this research assess the conflict in Mali from January 2012 to 11 January 2013 (Pre-French Intervention, Chapter Four) and from 11 January 2013 to 11 February 2013 (Post-French Intervention, Chapter Five). The first example identified the relationship between Ansar Al-Din and the MNLA as being under particularly high tension to change. After the French intervened, the Ansar Al-Din group split in two; one group stayed with the Islamic extremist subgroup and the other group (IMA) became allied more closely with the MNLA. This split was likely due to the tension identified by employing the methodology on the Chapter Four model. In the post-

French Intervention example of Chapter Five, two main subsets were identified; the Islamic militants and the International forces. The MNLA/IMA is a third subset and determined to be the mediator between the two main subsets. It is likely the Malian government will be reliant on the International forces and the MNLA/IMA to help them fight the Islamic militants for the foreseeable future. This provides the MNLA/IMA the ability to leverage this role to achieve more autonomy for the Tuareg in Northern Mali.

6.4   Recommendations for Future Research

This research offers a starting point for the modeling and analysis of signed social networks with military applications. There are many plausible areas to expand this methodology with future research.

While this methodology advances analysis by evaluating signed network data, it would be useful to assess the strength of the tie in addition to the sign. Instead of just having -1, 0, and 1 as tie strength, it would provide much more insight if the strength of tie could be any continuous number from -1 to 1, where the extremes are strong relations and zero is no relation. Having continuous numbers would essentially weight the tie putting more confidence and importance on relations that are known to be stronger. While the examples used in this research did not take into account directional relations, the methodology does support the ability to analyze directional ties.

Assessing signed dark networks is possible using this methodology as well. However, relations between certain actors within dark networks are often times

unknown. If a partial signed dark network is known, unknown relations could be propagated using techniques similar to Guha *et. al.* (2004). In this manner potential relations could be hypothesized to populate the unknown parts of the network. As relations are revealed, the network can be updated for better results. If results do not match what is predicted by the network, sources of tension, mediating parties, and alliances could be identified through inconsistencies in the network.

This methodology identified specific relations and actors that were unique to the network in order to decrease conflict within the network. In other words it attempted to identify ways to make the network more stable. However, this methodology could be altered to identify ties that are vulnerable in order to make a network less stable. Less stable enemy networks can slow down the enemy's ability to act.

6.5 Conclusions

The United States military is often called to operate in unknown places throughout the world. Each place has its own unique set of actors and web of relations between those actors. This research provides a methodology for assessing complicated relationships in a setting where conflict is evident by assessing the positive and negative relations between key actors. Groups of actors, mediators and relations vulnerable to change can be identified to provide insight into complex networks. It provides another tool in the analyst's repertoire to assist in identifying key relations and suggesting potential causes of action.

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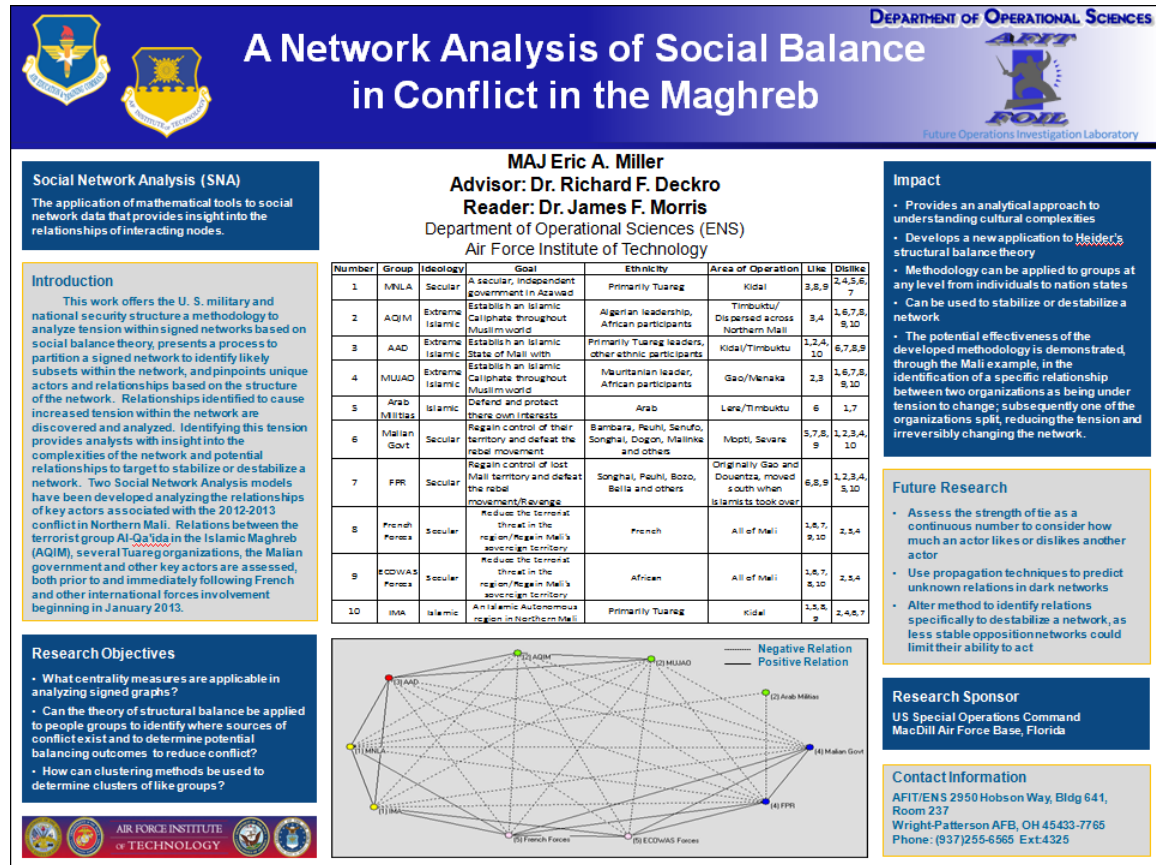
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Vita

Major Eric A. Miller graduated from Argo Community High School in Summit, Illinois in 1998. He was accepted to the United States Military Academy at West Point where he graduated in 2002 with a Bachelor of Science degree in Human/Regional Geography. Upon graduation he was commissioned into the U.S. Army Engineer Regiment. His first assignment was as a platoon leader in the 2nd Engineer Battalion in Camp Castle, South Korea. In 2004, he was assigned to the 3-10 Infantry Regiment at Fort Leonard Wood, Missouri as a Company Executive Officer. In 2006, Major Miller earned a Master's degree in Engineering Management from Missouri University of Science and Technology. Upon graduation, Major Miller was assigned to the Headquarters, U.S. Army Pacific where he served as a battle captain in the Joint Operations Center. In the 84th Engineer Battalion at Schofield Barracks, Hawaii, Major Miller was first the battalion logistics officer and then a company commander from 2007 to 2011. While in the 84th Engineer Battalion, he deployed to Mosul, Iraq for one year. In 2011 Major Miller served as an Assistant Operations Officer in the 130th Engineer Brigade at Schofield Barracks, Hawaii. In September 2012, he entered the Graduate School of Engineering and Management, Air Force Institute of Technology. Upon graduation, he will be assigned to the U.S. Army Human Resources Command at Fort Knox, Kentucky.

Appendix A: Quad Chart

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14. ABSTRACT

This work offers the U. S. military and national security structure a methodology to analyze tension within signed networks based on social balance theory, presents a process to partition a signed network to identify likely subsets within the network, and pinpoints unique actors and relationships based on the structure of the network. Relationships identified to cause increased tension within the network are discovered and analyzed. Identifying this tension provides analysts with insight into the complexities of the network and potential relationships to target to stabilize or destabilize a network. Two Social Network Analysis models have been developed analyzing the relationships of key actors associated with the 2012-2013 conflict in Northern Mali. Relations between the terrorist group Al-Qa'ida in the Islamic Maghreb (AQIM), several Tuareg organizations, the Malian government and other key actors are assessed, both prior to and immediately following French and other international forces involvement beginning in January 2013. The potential effectiveness of the developed methodology is demonstrated, through the Mali example, in the identification of a specific relationship between two organizations as being under tension to change; subsequently one of the organizations split, reducing the tension and irreversibly changing the network.

15. SUBJECT TERMS
Social Balance Theory, AQIM, Mali, Blockmodeling, Social Network Analysis

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